2007-12

A model-based optimization plan for the F-16 pilot training

Mise, Murat

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A MODEL-BASED OPTIMIZATION PLAN FOR THE F-16 PILOT TRAINING

by

Murat Mise

December 2007

Thesis Advisor :	Uday Apte
Thesis Co-Advisor:	Aruna Apte

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

<table>
<tr><td colspan="3">REPORT DOCUMENTATION PAGE</td><td colspan="2">Form Approved OMB No. 0704-0188</td></tr>
<tr><td colspan="5">Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.</td></tr>
<tr><td colspan="2">1. AGENCY USE ONLY (Leave blank)</td><td>2. REPORT DATE
December 2007</td><td colspan="2">3. REPORT TYPE AND DATES COVERED
Master’s Thesis</td></tr>
<tr><td colspan="3">4. TITLE AND SUBTITLE
A Model-Based Optimization Plan for the F-16 Pilot Training</td><td colspan="2" rowspan="2">5. FUNDING NUMBERS</td></tr>
<tr><td colspan="3">6. AUTHOR(S) Murat Mise</td></tr>
<tr><td colspan="3">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000</td><td colspan="2">8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="3">9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A</td><td colspan="2">10. SPONSORING/MONITORING AGENCY REPORT NUMBER</td></tr>
<tr><td colspan="5">11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.</td></tr>
<tr><td colspan="3">12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited</td><td colspan="2">12b. DISTRIBUTION CODE</td></tr>
<tr><td colspan="5">13. ABSTRACT (maximum 200 words)

Pilot training is the most critical factor that determines the fighting capability of the Air Force. It is a very costly, lengthy and complex process, and therefore very hard to manage. The fighting capability today is the result of the hiring and training decisions made many years ago. Therefore, anticipatory planning is very important in pilot training, to reduce costs and increase fighting capability.
The purpose of this project is to model and optimize the F-16 pilot training progression as a supply chain where each step in the process is seen as the “supplier” of the next step. The attritions and reassignments of the pilots make this model complicated and there are also the constraints of scarce training resources such as instructors and equipment. The purpose of this project is to develop a model-based approach for reducing the cost of pilot training while improving the fighting capacity of the Air Force. In this research we develop a linear programming model to synchronize and balance the flow of pilots through the various stages of the supply chain. The model includes constraints such as capacity and manpower flows reflecting hiring and training of pilots. The optimization model is then tested and illustrated through a computational experiment based on realistic yet hypothetical data.</td></tr>
<tr><td colspan="4" rowspan="2">14. SUBJECT TERMS
F-16 pilot training, supply chain management, linear programming, optimization, manpower planning</td><td>15. NUMBER OF PAGES
71</td></tr>
<tr><td>16. PRICE CODE</td></tr>
<tr><td>17. SECURITY CLASSIFICATION OF REPORT
Unclassified</td><td colspan="2">18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified</td><td>19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified</td><td>20. LIMITATION OF ABSTRACT
UU</td></tr>
</table>

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

A MODEL-BASED OPTIMIZATION PLAN FOR THE F-16 PILOT TRAINING

Murat Mise
Lieutenant Junior Grade, Turkish Navy
B.S., Turkish Naval Academy, 2002

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2007

Author: Murat Mise

Approved by: Uday Apte
Thesis Advisor

Aruna Apte
Thesis Co-Advisor

Robert Beck
Dean, Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Pilot training is the most critical factor that determines the fighting capability of the Air Force. It is a very costly, lengthy and complex process, and therefore very hard to manage. The fighting capability today is the result of the hiring and training decisions made many years ago. Therefore, anticipatory planning is very important in pilot training, to reduce costs and increase fighting capability.

The purpose of this project is to model and optimize the F-16 pilot training progression as a supply chain where each step in the process is seen as the “supplier” of the next step. The attritions and reassignments of the pilots make this model complicated and there are also the constraints of scarce training resources such as instructors and equipment. The purpose of this project is to develop a model-based approach for reducing the cost of pilot training while improving the fighting capacity of the Air Force. In this research we develop a linear programming model to synchronize and balance the flow of pilots through the various stages of the supply chain. The model includes constraints such as capacity and manpower flows reflecting hiring and training of pilots. The optimization model is then tested and illustrated through a computational experiment based on realistic yet hypothetical data.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I. DEFINITION OF THE PROBLEM AND RATIONALE 1
- A. BACKGROUND 1
- B. RESEARCH OBJECTIVES 2
- C. SCOPE 3
- D. RESEARCH METHODOLOGY 3
- E. PROJECT ORGANIZATION 4

II. PILOT TRAINING PROCESS 5
- A. THE PILOT TRAINING SUPPLY CHAIN 5
  - 1. Undergraduate Pilot Training (UPT) 6
  - 2. Operational Conversion Unit (OCU) Training 8
  - 3. Wingman 8
  - 4. 2-Ship Flight Lead 9
  - 5. 4-Ship Flight Lead 9
  - 6. Mission Commander (MC) 10
  - 7. Instructor Pilot (IP) 10
- B. THE ORGANIZATION OF THE USAF F-16 SQUADRONS 10
- C. TRAINING SPECIFICATIONS 11
  - 1. Types of Training 11
  - 2. Inexperienced vs. Experienced Pilots 12
  - 3. CMR vs. BMC Pilots 12
  - 4. Sortie Requirements 13
  - 5. Instructor Pilot (IP) Supervision Requirements 14
  - 6. Attrition and Turnover 15
- D. TRAINING COSTS 16
  - 1. Cost of Flying Hours 16
  - 2. Composite Cost of the Pilots 17

III. OPTIMIZATION MODEL 19
- A. OBJECTIVE FUNCTION 22
- B. DECISION VARIABLES 24
- C. CONSTRAINTS 24
- D. MODELING IN MICROSOFT EXCEL 27
  - 1. “Inputs-Outputs” Sheet 27
  - 2. “Tables” Sheet 29
  - 3. “Optimization Model” Sheet 29
- E. SIMULATION SPECIFICATIONS 30
  - 1. Hardware 30
  - 2. Software 30
  - 3. Elapsed Time 31

IV. COMPUTATIONAL EXPERIMENT AND RESULTS 33
- A. SIMULATION METHODOLOGY 33

1. Demand for F-16 Pilots under Different Threat Levels 34
2. Historical Data Approach 35
3. Analysis with Input Analyzer 37
4. Generating Random Scenarios Using Input Analyzer 39
B. RUNNING THE SIMULATION....................40
C. RESULTS 42
1. Total Training Costs....................42
2. Impact of Planning Horizon Length on the Number of Pilots.......44
3. Importance of Starting Inventory 46
4. Cost of Attrition and Turnover 47
5. Length of the Pilot Training Progression 48
V. CONCLUSION AND RECOMMENDATIONS....................49
A. CONCLUSIONS 49
B. RECOMMENDATIONS....................50
C. SUGGESTIONS FOR FUTURE RESEARCH....................52
LIST OF REFERENCES 53
INITIAL DISTRIBUTION LIST 55

LIST OF FIGURES

Figure 1. Stages of the F-16 pilot training supply chain. 6
Figure 2. Average Attrition Rates by Years of Service (From Bookheimer, 1996).............16
Figure 3. The stocks and flows of the manpower system in the F-16 Pilot Training Supply Chain...21
Figure 4. Input tables of the Inputs-Outputs sheet. 28
Figure 5. Output table of the Inputs-Outputs sheet. 28
Figure 6. Optimization Model sheet...30
Figure 7. Color coding of the timeline of U.S. history since 1950 36
Figure 8. Distribution summary of the historical input data 38
Figure 9. New scenario generation tool...39
Figure 10. Data summary of newly created scenarios..41
Figure 11. Scatter diagram of total training costs 43
Figure 12. Diminishing marginal utilities in total pilot training costs 44
Figure 13. Comparison of myopic and long-term pilot inventory levels 46
Figure 14. Average required number of pilots in the first four years of each scenario..........47
Figure 15. Average required number of pilots in the last three years of each scenario 47

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1. Flying hour rates used in the model 17
Table 2. Annual composite costs of the pilots of different levels 18
Table 3. Notation for the manpower system in pilot training 19
Table 4. Demand for F-16 pilots under different threat levels 35
Table 5. A sample of newly created random scenarios 40

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGEMENTS

This thesis is dedicated to my beloved father whom I have lost during my study at the Naval Postgraduate School. He has always supported and encouraged me for everything I have done in my life and I have always tried to do my best to make him proud. God bless his soul.

I am very grateful to my thesis advisors Professor Uday Apte and Professor Aruna Apte for their valuable guidance, insight and support for this thesis. This thesis would never reach the levels of quality that it has now without their help.

Last of all, I would like to thank my lovely wife Ozge for her love, patience and support throughout my entire study at the NPS.

THIS PAGE INTENTIONALLY LEFT BLANK

I. DEFINITION OF THE PROBLEM AND RATIONALE

A. BACKGROUND

Although the history of the Air Force dates back to 1907; the Air Force as an independent service was established 60 years ago in 1947. Back then, its main duty was primarily to support the operations of the Army and the Navy. As time passed, Air Force capabilities have improved and it has become a critical force on the battle field. As owner of the most superior weapon systems and advanced high technology assets, the Air Force plays an extremely important role in safeguarding the sovereignty and security of the nation. The right combination of aircraft, weapon systems, reliable information technology, skilled pilots and ground crew determines the fighting capability of the Air Force. The most important of all of these factors is definitely the human factor: the pilots.

Pilots go through a very lengthy and difficult training process in order to become a qualified fighter. The pilots have a tiered training progression which moves them from one qualification to another. There are seven steps in this process and it takes as much as eight years to climb up to the highest level. The pilots spend most of their time in training, in order to be ready whenever their service is needed. It is also the main objective of the operational squadrons to maintain readiness to deploy and operate in wartime, contingencies, and other engagements.

With a complicated and lengthy training process, the number of available pilots and the readiness level of these pilots today is the result of the hiring and training decisions that were made many years ago. Therefore, it is very important to develop an anticipatory decision making model for hiring and training of pilots so that necessary number are ready with required capabilities when they are needed.

The pilot training process is very similar to a traditional manufacturing supply chain process, where outputs of one step are the inputs for the next step. The pilot training supply chain has basically two major challenges. The first one is having the right number of trained pilots of different capabilities available when needed. While it is very costly to train and maintain skill levels of a pilot, having an excess of trained pilots is unnecessarily expensive. It is also unacceptable to have a shortage of trained pilots when necessary. The second challenge is maintaining a smooth flow of pilots through the various stages of the supply chain. For example, if too many pilots are trained in an early stage (beyond the requirements and capacities of the next stage), this situation becomes unnecessarily expensive and would generate no benefit in increasing the fighting capability of the Air Force. Such a situation typically leads to non-flying assignments for some pilots, which requires re-qualification training with additional costs. Ground assignments lower the job satisfaction of the pilots, as well, which leads to shorter pilot careers and reduces the return on investment for the Air Force. The unpredictable attrition and turnover rates, together with the scarce training resources make it more difficult to effectively model the flow of pilots through the supply chain.

In addition to achieving optimal levels of trained pilots, lowering the costs and investments is another important goal. This will also be developed as part of planning methodology. Once a smooth flow is achieved, the excess inventory of pilots will be eliminated without reducing the readiness levels. With the elimination of excess inventory, it will be possible to train the remaining pilots better while reducing the overall costs, which is an additional advantage.

B. RESEARCH OBJECTIVES

The main objective of this project is to design a model for the pilot training supply chain, in order to achieve a desired readiness level with the least cost possible. This will be achieved by:

- formulating an optimization model which best represents the pilot training supply chain
- testing the model under different scenarios which will show the nature of tradeoffs associated with strategic decisions in optimizing the supply chain.

C. SCOPE

The study area of this project will be modeling the pilot training supply chain and evaluating this model under different scenarios. Due to the great variety of pilot types in the U.S. Air Force, it is not possible to create a model that fits the training progressions of all of these different pilot types. The steps, training requirements, and constraints of these pilots are quite different. Therefore, we choose to model the training process of F-16 pilots and its specific requirements. However, due to the richness and flexibility of the model, it is possible to make small modifications and use it for the training processes of other pilots in the Air Force as well as in other branches of the DoD.

D. RESEARCH METHODOLOGY

The overall research methodology consists of the following steps:

- Reviewing the published literature and conducting personal interviews, if feasible
- Defining the pilot training supply chain by analyzing sample data collected through the interviews and literature review
- Formulating the optimization model
- Testing the model under different scenarios and generating recommendations

The pilot training supply chain will be modeled as a multi-period linear programming optimization model. The fundamental decision variables will be the numbers of newly hired pilots, the numbers of Combat Mission Ready (CMR) pilots, and total flying hours flown by the pilots, in any time period. Due to promotions, attrition and turnover, the number of pilots at any given level can vary over time. A set of equations will be formulated that captures, over multiple time periods, the relationship between the numbers of hires and pilots in various stages of the training process. The model will also include equations representing various constraints, such as training capacity, currently existing in the training program. The model will be based on some assumptions (e.g., how long it takes pilots to progress from one stage to the next, the flight requirements in order to become CMR, and the costs of pilot inventories). It will also be based on the factors such as attrition and turnover which change the number of pilots available at any level, and constraints on training resources (instructors and equipment). Equations modeling these issues will form the constraint set for the multi-period pilot training supply chain optimization model.

E. PROJECT ORGANIZATION

The organization of the project is as follows:

Chapter II provides a detailed description of the pilot training process. Different steps of the process are described in detail, providing a good understanding to the readers who are not familiar with the process. Different features of the process—such as attrition, turnover, promotion, cost of training, composite costs, and flight requirements—are explained clearly.

Chapter III covers the mathematical model and the formulations. Different equations are created to represent the supply chain in the best way. The objective function, decision variables and constraints of the model are also defined. Based on these equations, a multi-period linear programming model is designed using Microsoft Excel. Finally, the characteristics of this model and the spread-sheet workbook are explained in this chapter.

Chapter IV provides the computational experiment and results. Many different scenarios are created to evaluate the model and determine the trade-off between cost and readiness. For the evaluation of the model, a different workbook is created by using Microsoft Excel as a user file. The macros in this workbook that are created by using Microsoft Visual basic programming language help the user to easily run the model multiple times. With the help of this workbook, 1,000 different scenarios are created and the solutions of the optimization model are recorded. At the end, a chart which shows the relation between cost and readiness is prepared by using these computational results.

Chapter V offers the conclusions and recommendations based on the model and the results. Suggestions for future research are also included.

II. PILOT TRAINING PROCESS

In this chapter, the pilot training process is described in detail. The training progression of F-16 pilots is defined as a supply chain. Different steps of this progression are described in detail, providing explanation to readers who are not familiar with the process. Different features of the process, such as attrition, turnover, promotion, cost of training, composite costs, and flight requirements are described.

A. THE PILOT TRAINING SUPPLY CHAIN

The Air Force website states that there are 10 different types of pilots in the Air Force, all requiring different training programs of different lengths and specifications. Due to this great variety, it is not possible to create a model that fits the training processes of all of these different pilot types. F-16s account for the majority of Air Force fighter aircraft. Therefore, we model the organizational structure of the F-16 squadrons and training process of their pilots. Even within the F-16 squadrons, there are huge differences in organizational structure and training requirements. Therefore, a generic F-16 squadron is created and used in this study to develop the model and methodology. However, it is possible to make modifications in the model and use it for the training process and other organizational structures—not only in the Air Force but also in other branches of the DoD.

The F-16 pilots have a tiered training progression which moves them from one qualification to another. The training regimen is very similar to a seven-stage supply chain, which can broadly be separated into two categories: Initial Pilot Training (IPT) and Pilot Training in Operational Squadrons.

The IPT is the initial training before pilots are assigned to their operational squadrons. There are two stages in the IPT: Undergraduate Pilot Training (UPT) in the first year and Operational Conversion Unit (OCU) training in the second year. Once the IPT is completed, the pilots are assigned to their first operational squadrons. In an operational squadron, there are five stages of progression: 1) Wingman, 2) 2-Ship Flight

Lead, 3) 4-Ship Flight Lead, 4) Mission Commander, and 5) Instructor Pilot. These categories and the stages in these categories are depicted in Figure 1 and described in detail below.

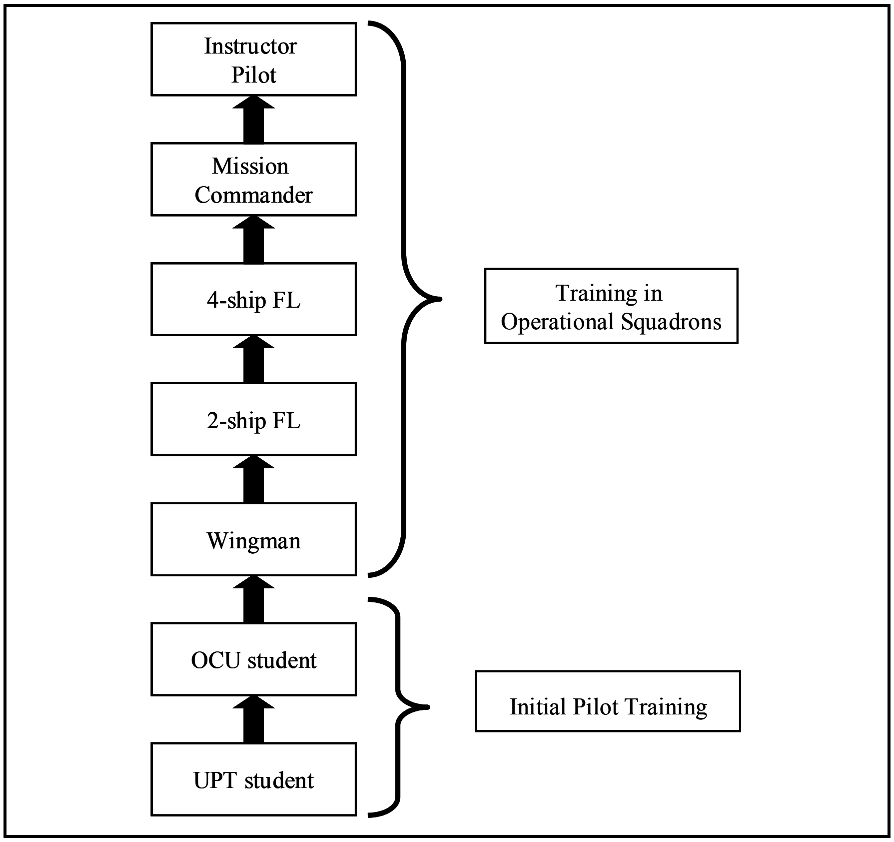

Figure 1. Stages of the F-16 pilot training supply chain.

1. Undergraduate Pilot Training (UPT)

The IPT starts with the UPT in the first year. The UPT is also referred as the "Pipeline Training." The Base Operations website (www.baseops.net) provides detailed information about the UPT. Based on the information provided on this website, in the first phase of the UPT the students take mostly academic classes and pre-flight training. The classes cover subjects such as: Aerospace Physiology, Altitude Chamber Rides, Aircraft Systems, Basic Instruments, Mission Planning & Navigation, etc. The students also use flight simulators to practice what they learn in academic classes and to get familiar with the cockpit environment.

After completing the first phase successfully, the students pass to Phase 2, Primary Flight Training (PFT). The main purpose of this phase is to teach the students basic flying skills. In this phase, the students fly an aircraft for the first time. The students fly the T-37 or T-6 aircraft for approximately 90 hours of flight training instruction.

After completion of the first two phases in approximately 6 months, students pick the Advanced Track they wish to fly, but the selection is based on their performances in the second phase and Air Force needs. Students request their track preferences and the flight commander decides the track placement. However, the students can only pick their tracks at this level, not the aircraft.

If a student picks the Fighter/Bomber track, then he continues to the 3rd phase with the T-38 aircraft. The third phase takes another six months and requires approximately 120 hours of flight instruction. The purpose of the third phase is to prepare graduates for fighter/bomber assignments. The training in this phase concentrates on low-level tactics, instrument procedures, 2- and 4-ship formation flying and navigation training. When the third phase is finished, the students pick the follow-on aircraft based on merit and instructor recommendation. The students can choose from the F-16, F-15C, F-15E, A-10, B-1, B-52, and B-2 airframes.

The UPT program lasts approximately 52 weeks. The students fly a total of about 50 hours in the UPT. After successfully completing the UPT, officers receive their silver wings and are awarded the aeronautical rating of pilot. They attend follow-on training in their assigned aircraft at various bases around the country. If a pilot is assigned to an F-16 aircraft, he goes to the Luke Air Force Base (AFB), Arizona where the F-16 Fighting Falcon follow-on training is given.

2. Operational Conversion Unit (OCU) Training

The F-16 Operational Conversion Unit (OCU) training is provided at Luke AFB, AZ. According to the information on the Luke AFB website, the OCU training starts with a heavy load of academic classes. These classes are accompanied by hands-on simulator training which helps cockpit familiarization. After several weeks of academics, the students fly an F-16 for the first time with the two-seated F-16D model. Once the students are cleared for solo flight, they continue with the single-seated F-16C model. In the first couple of weeks with the F-16C, students become competent at flying the aircraft in formation, acrobatic maneuvers, etc. and then move on to the next phase.

The next phase provides instruction on Air-to-Air combat. The students learn to use the aircraft's fire control systems correctly and skillfully while practicing advanced maneuvering tactics. They also learn interception techniques against air targets.

In the advanced stages of the OCU training, students take the Air-to-Ground training, which covers how to destroy ground targets by using the aircraft's 20mm cannon and by dropping bombs. Then they learn how to fly and operate at night by using the night vision goggles. The final phase of OCU is the Surface Attack Tactics, which is a combination of all of the previous courses. In this phase, the students fly as part of a large force and fight against a defended target area.

After approximately 12 months of intense training including over 265 hours of classroom instruction, 55 hours of simulator and 80 hours of flight time, the students graduate as the Air Force's newest F-16 fighter pilots. They then are assigned to their first operational base and the follow-on training continues based on the specific duty assignments of the operational squadrons.

3. Wingman

The first assignment to an operational squadron is with the rank of Wingman. The Wikipedia online dictionary describes a Wingman as:

> a pilot who supports another in a potentially dangerous flying environment. Wingman was originally a term referring to the plane flying

> beside and slightly behind the lead plane in an aircraft formation. The idea behind the Wingman is to add the element of mutual support to aerial combat. A wingman makes the flight both offensively and defensively more capable by increasing fire power, situational awareness (hopefully), attacking an enemy threatening a comrade, and most importantly the ability to employ more dynamic tactics.

Crenshaw (1999) states that:

> wingmen have the supporting role in a flight. They help the leader plan and organize the mission. They have visual lookout and radar responsibilities, and perform backup navigation tasks. Wingmen engage as briefed or when directed by the leader and support when the leader engages. It is essential that the wingmen understand their briefed responsibilities and execute their offensive or defensive contract in a disciplined manner.

4. 2-Ship Flight Lead

Rennspies (2002) notes that the Flight Lead is "in command" both on the ground and in the air. He is responsible for not only his own, but also for his Wingman's aircraft. He has the general responsibility for planning and organizing the mission, leading the flight, and delegating tasks within the flight to ensure the mission is safely accomplished. On the ground, the flight lead will plan, brief and debrief the mission. He may delegate tasks within the flight. Once airborne, he has the final responsibility for navigating, communicating, formation airmanship and leading the flight successfully through the mission.

5. 4-Ship Flight Lead

The job description of a 4-ship Flight Lead is very similar to a 2-ship Flight Lead. The 4-ship Flight Lead is the leader of four aircraft in a formation. He is responsible not only for his aircraft, but also for the other three aircraft under his command. He is both a 2-ship lead and a 4-ship lead depending on the situation and mission requirements. He also has the general responsibility for planning and organizing the mission, leading the flight, and delegating tasks within the flight to ensure the mission is safely accomplished.

6. Mission Commander (MC)

The Mission Commanders is the leader of a flight group. He has the overall authority, control, and coordination to accomplish the mission. In peace time, the focus of his attention is mostly on the administrative procedures of rules and regulations, the operational management of outlined training plans. He is also responsible for the safety of his aircrew and needs to ensure that they are keeping their proficiency level as high as possible.

7. Instructor Pilot (IP)

Instructor Pilots are the most proficient and experienced pilots in an operational squadron. They are specially selected among all pilots and must be graduates of the Air Education and Training Command's pilot instructor training program. They must meet rigid personal, flying and other professional standards. Their job is to share their knowledge and experience with the inexperienced/less experienced pilots. The IPs train the upgradee pilots first and then evaluate their performance, either from the rear cockpit or from a chase aircraft. Most of the sorties that the IPs fly are for the supervision of other pilots.

The seven-stage path of F-16 pilot training, starting from UPT up to IP takes eight years on average. While some pilots climb it faster, it takes more time for others. Some highly talented pilots can be assigned as a 4-ship flight lead right after completion of wingman training. In this study, it is assumed that each stage in the training progression takes exactly one year and the whole process is completed in seven years in total.

B. THE ORGANIZATION OF THE USAF F-16 SQUADRONS

Bigelow, Taylor, Moore and Thomas (2003) define that by January 2001, there were 21 operational F-16C squadrons in the active duty component, 25 squadrons in the Air National Guard and 4 squadrons in the Air Force Reserve. The numbers of authorized aircraft were 420, 375, and 60, respectively. Based on the mission of the squadron, some active squadrons have 18 primary aircraft while others have 24. In this study, a generic F-16 squadron which has 20 primary aircraft is used for the modeling purposes.

In an operational squadron the crew ratio is 1.25, which means there are 1.25 pilots in every squadron for each cockpit position. Therefore, in a squadron with 20 primary aircraft, there are 20*1.25=25 pilots. Of these pilots, two are Instructor Pilots, four are Mission Commanders, five are 4-ship Flight leads, seven are 2-ship Flight Leads, and seven are Wingmen. Non-flying billets for ground elements are excluded from the scope of this study.

The grade structure of these pilots in the generic squadron are assumed as follows: Instructor Pilots are O-5s, Mission Commanders are O-4s, 4-ship Flight Leads are O-3s and 2-ship Flight Leads and Wingmen are O-2s. These numbers represent the general grade structure of the squadron and are used in equations in the further chapters. However, there exist cost differences between same-ranked pilots due to differences in service years. The annual pay and composite cost of an O-2 with four years of service is more than that of an O-2 with two years of service. Though these differences are small, they are considered while preparing the cost structure of the pilots.

C. TRAINING SPECIFICATIONS

1. Types of Training

The fighter squadrons have two missions. The primary mission is to deploy and conduct combat missions during wartime, and the second mission is to train and to provide operational knowledge to the fighter pilots. The Air Force philosophy for training has been that all squadrons will be ready for war at any given time. Thus, the fighter squadrons spend most of their time in training. It is a common perception of combat readiness that the more often the sorties, the better prepared the squadrons.

Pilot training in operational squadrons can be divided into two broad categories:

a. *Continuation training* ensures that the pilots maintain and sustain the skills required to perform the squadron's assigned missions. Continuation training is necessary for the pilots to keep their flying positions.

b. *Upgrade training* prepares the pilots for the next level in the career chain of pilots, from wingmen to 2-ship flight leads, to 4-ship flight leads, to mission commanders, and finally to instructor pilots. The process of upgrading in the operational squadrons can take up to six years under normal conditions. However, it is assumed in this study that each upgrade takes exactly one year, with a total of five years.

2. Inexperienced vs. Experienced Pilots

The Ready Aircrew Program (RAP) of the Air Force determines the minimum numbers and types of sorties that the pilots should fly to maintain their proficiency and upgrade to higher levels. Based on the directions of the RAP, the F-16 squadrons build their own flying hour programs for the number of sorties needed every year. Generally, inexperienced pilots are allocated more sorties than the experienced ones so that the overall readiness level of the squadron goes up. The common criteria for distinguishing experienced pilots from inexperienced ones is that experienced pilots have accumulated at least 500 flying hours in their primary mission aircraft. The distinction between experienced and inexperienced pilots is disregarded in this study and an approximate number is used for the sortie requirements of every type of pilot.

3. CMR vs. BMC Pilots

Air Force Instruction (AFI) 11-2F-16 categorizes a pilot as Combat Mission Ready (CMR) if he is "qualified and proficient in all of the primary missions tasked to his assigned unit and weapon system." A pilot is considered Basic Mission Capable (BMC) if he is "familiarized in all, and may be qualified and proficient in some of the primary missions tasked to his assigned unit and weapon system." The difference between these two types of pilots is that BMC pilots need some spin-up sorties to be ready for combat while CMR pilots are assumed to be ready for combat any time with no spin-up requirement.

Based on this information, one purpose of this model is to assure that all pilots keep their CMR status. A BMC pilot has a negative effect on the readiness level of the squadron; therefore, this is not a desired situation. The sortie requirements explained below are based on the requirement that all pilots should keep their CMR status.

4. Sortie Requirements

The determination of sortie requirements that allow all of the pilots to keep their CMR status is in fact a very complex procedure. Each squadron is required to have a minimum number of different types of pilots (e.g., wingman, flight leads, instructor pilots, etc.) who have been trained for different special skills. There are a lot of issues that are considered during calculation of the sortie requirements, such as experience levels of the pilots, jobs of the pilots in the squadron, sortie profiles and versions, skill acquisition of the pilots, etc. Hence, the annual flight hour program of each squadron is unique to that unit.

Many scientific researches and studies have been held in the past to optimize the sortie requirements of the operational squadrons with the least cost possible. The results of these studies vary depending on their ability to reflect the real life situation. One respectable study was held by the RAND Institute in 2003 for planning of the numbers of sorties to be flown in the operational squadrons (Bigelow, et al., 2003).

The RAND study also states that the determination of "adequate training" is hard to make. Adequate training means training that is good enough that there will be no need for spin-up sorties before performing the assigned missions. However, there is a huge gap in the perceptions of pilots on how much training is adequate. While some interviewed pilots estimate that 10 sorties per month are enough, others think that 15 sorties are required every month so that adequate training is given to the pilots. Because of this huge difference in perceptions of "adequate training," the findings of the RAND report are used in this study for determination of the sortie requirements.

The results of the RAND study show that 13 sorties per month per pilot are enough to gain all the skill sets and meet the mission requirements for any type of pilot. Considering that the duration of a sortie is 1hour 40minutes on average; the flight requirement for each pilot sums up to 260 flight hour annually (13 sorties/month * 12 months/year * 1.66 hours/sortie = 260 hours/year). This number is used as the quality constraint which ensures that all pilots are mission ready and keep their CMR status at all times.

5. Instructor Pilot (IP) Supervision Requirements

It was stated earlier that each pilot flies sorties either as continuation training or upgrade training. When a pilot first joins an operational squadron, he must complete the mission qualification training (MQT). Once the MQT is finished, the pilots start skill acquisition for an upgrade. Upgrade is basically the process which prepares the pilots for the next job or mission. In other words, skill acquisition via upgrade training is necessary for the promotion of pilots from wingman to flight lead, from flight lead to mission commander, etc.

Each upgrade consists of a specified sequence of sorties flown by the upgradee under the supervision of an IP. Mostly, the first sortie in a sequence is supervised by the IP. After fulfillment of the required sorties of a skill by the upgradee, the final sortie is also supervised by an IP as a final exam. A very small fraction of upgrade sorties can be supervised by a 4-ship flight lead, but this small possibility is ignored in this study.

Bigelow, et al. (2003) define that the sortie profiles and therefore supervision requirements vary significantly among different types of squadrons. Based on the sortie profiles of an F-16 LANTIRN (Low Altitude Navigation and Targeting, Infrared for Night) squadron, 15 out of 22 sortie profiles are upgrade profiles which must be flown under the supervision of an IP. With a supervision requirement rate of 1.75 (all of the final sorties plus 75% of the first sorties) approximately 26 (15*1.75=26) sorties must be supervised by an IP.

Given that each pilot must fly at least 156 sorties (i.e., 260 flying hours) annually; the supervision requirement is equal to 44.2 flying hours, or 17% (26 sorties/156 sorties per year) of all sorties flown in a particular year. The supervision requirement in an operational squadron is valid for the wingman, 2-ship flight leads and 4-ship flight leads only. The supervision requirement is the most critical constraint in the training capacity of a squadron and is taken into account during mathematical formulations in Chapter III.

Although the instructor pilot is part of the pilot training supply chain, he is the key element in determination of training capacity of a squadron. Therefore, the number of instructor pilots in a squadron determines the training capacity of that squadron and also the readiness levels of the pilots. However, the instructors have their own limits and they cannot fly more than a certain amount in a year. Higer, M. (2007) states that an instructor can fly at most one sortie per day, which means that each instructor pilot can instruct 260 sorties per year (1 sortie/day * 5 days/week * 52 weeks/year = 260 sorties/year). Considering that each sortie takes on average 1.66 hours, the training capacity of an instructor pilot is 433.3 flight hours/year (260 sorties/year * 1.66 hours/sortie = 433.3 hrs/year).

6. Attrition and Turnover

Attrition is a term used for the expression of the loss of aircrew. The attrition rates for the aircrew became very high in the past and the Air Force fell into crisis. The most important reason for pilot attrition is low morale and motivation. The most critical reason for low motivation is the assignment of pilots to non-flying jobs. Bad planning of manpower leads to excess inventory of pilots and this may result in non-flying assignments for the pilots. A “grounded’ pilot needs re-qualification training to regain his old capabilities. This study aims to increase the satisfaction rate of the pilots and decrease the attrition rates by successful manpower planning. Economic factors and civilian recruitment are the also other important reasons for pilot attrition.

Turnover, which is the loss rate of employees, is also very high in the operational squadrons due to assignments to other jobs and squadrons within the Air Force. A high turnover rate is undesirable because it is another factor which lowers the motivation of the pilots. A pilot who is assigned to a different squadron needs to start his training from the very beginning, based on the mission of his new squadron. It is a very costly and lengthy process to regain the previous qualifications that the pilot had. In some occasions, it may take as long as two years to reach the same level.

The attrition rates are very high in the Air Force compared to private business averages. The Air Force considers an 8-10% attrition rate acceptable for the student pilots. The attrition rate among pilots gets even higher once their mandatory service is over. The attrition rates hit the peak when the pilots are at the Years of Service (YOS) 6 to 8. After a big wave of separation, the attrition rates fall down to 5-10% in the next years.

In this study, an attrition and turnover rate of 10% is used for the first four steps of pilot training progression. For the next three steps, an attrition rate of 30% is used in the mathematical model.

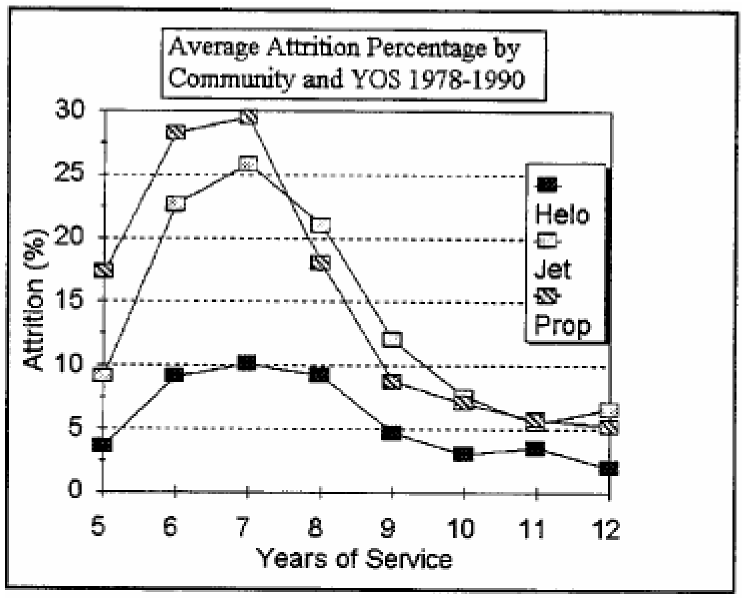

Figure 2. Average Attrition Rates by Years of Service (From Bookheimer, 1996)

D. TRAINING COSTS

1. Cost of Flying Hours

The high cost of flying requires that the commanders calculate a Flying-Hour Program (FHP) for planning. The number of required hours is determined at the major commands as a FHP annually, so that the budget will provide at least the minimum number of flying hours that are needed to maintain a certain level of readiness in the operational squadrons.

A Government Accounting Office (GAO) publication (Observations on the Air Force Flying Hour Program, 1999) defines that the basis for flying hour funding is the number of programmed hours multiplied by the projected cost per flying hour rate. Each major command develops a cost per flying hour rate for each of the aircraft types in its inventory. The rates comprise three major program expense elements: depot-level repairable parts, consumable supplies, and aviation fuel. Depot-level repairable items are parts that can be repaired at a maintenance facility and are used in direct support of aircraft maintenance (e.g., aircraft engines). Consumables are generally defined as non-repairable supply items used by maintenance personnel in direct support of aircraft maintenance. Aviation fuel is the cost of fuel purchased to operate aircraft.

Based on the flying hour rates published by the Office of the Secretary of the Air Force, the following rates are used in this study for the calculation of flying costs. The rate for the Fiscal Year 1 (FY1) is rounded from the actual flying hour rates of the Office of the Secretary of the Air Force for FY2001 and then that number is compounded annually with a compounding rate of 5% for the following years.

Table 1. Flying hour rates used in the model

	Fiscal Years						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Flying Hour Rates	$5,200	$5,460	$5,733	$6,020	$6,321	$6,637	$6,968

2. Composite Cost of the Pilots

The second cost associated with training is the pilot inventory carrying cost. There is a cost for the DoD for each pilot who is serving in the operational squadrons.

The DoD uses the "military composite standard pay and reimbursement rates" for budgetary planning of the pilot costs.

The military composite standard pay and reimbursement rates are calculated by the Office of the Under Secretary of Defense (Comptroller) annually. The "Annual Department of Defense (DoD) Composite Rate" is used for determining the cost of military personnel for budget/management studies.

The annual DoD composite rate includes the following military personnel appropriation costs:

- Average basic pay plus retired pay accrual
- Medicare-eligible retiree health care accrual
- Basic allowance for housing
- Basic allowance for subsistence
- Incentive and special pay
- Permanent change of station expenses
- Miscellaneous pay

Based on the composite rates determined by the Office of the Under Secretary of Defense (Comptroller), the following annual costs are used in this study as the annual cost of the fighter pilots of different grades. The rates for the Fiscal Year 1 (FY1) of the model are rounded from the actual composite rates of the Department of the Air Force for FY2001, and then these rates are compounded annually with a compounding rate of 5% for the following years.

Table 2. Annual composite costs of the pilots of different levels

	Fiscal Years						
Pilot Levels	**1**	**2**	**3**	**4**	**5**	**6**	**7**
UPT student	$80,000	$84,000	$88,200	$92,610	$97,241	$102,103	$107,208
OCU student	$85,000	$89,250	$93,713	$98,398	$103,318	$108,484	$113,908
Wingman	$100,000	$105,000	$110,250	$115,763	$121,551	$127,628	$134,010
2-ship FL	$105,000	$110,250	$115,763	$121,551	$127,628	$134,010	$140,710
4-ship FL	$110,000	$115,500	$121,275	$127,339	$133,706	$140,391	$147,411
MC	$125,000	$131,250	$137,813	$144,703	$151,938	$159,535	$167,512
IP	$130,000	$136,500	$143,325	$150,491	$158,016	$165,917	$174,212

III. OPTIMIZATION MODEL

The pilot training supply chain will be modeled as a multi period Linear Programming (LP) model. This is because the decision makers have to determine the optimal number of new hires for several periods in the future. The difficulty of this approach is that the decision choices in the later periods are directly dependent on the previous decisions. The numbers of pilots we have today are the results of hiring decisions which were made several years ago.

The effect of hiring, promotion and attrition on the number of pilots can be modeled in a formal way. This will be accomplished by developing a set of equations representing the stocks and flows of manpower (Apte, 2007; Grinold and Marshall, 1977; Vajda 1978). The notation used in equations for manpower systems is given in Table 3.

Table 3. Notation for the manpower system in pilot training

$P_j(t)$	The observed number of pilots of level *j* in time period *t*
$InvP_j(t)$	The inventory of pilots of level *j* left after attrition at the end of time period *t*
$h(t)$	Number of new pilots being hired in time period *t*
β_j	The ratio of pilots at level j who are promoted to a higher level at time period *t*
δ_j	The turnover and attrition rate for pilots at level *j*
C_{FH}	Cost of a flying hour
$C_j(t)$	The annual composite cost of a pilot at level *j* in year *t*
$REQ_j(t)$	Required number of pilots of level *j* for time period *t*, in order to achieve the readiness level for time period *t*
$MIN_j(t)$	Minimum number of pilots of level *j* required for time period *t*, in order to achieve a continuous flow in the supply chain
$MAX_{ins}(t)$	Maximum hours that instructors can fly in time period *t*
$HOURS(t)$	Total flying hours flown by all levels of pilots in time period *t*
SI_j	Starting Inventory for level j pilots in year 1, for j = 2, 3, …, 7

Since the Air Force Command is able to increase the number of pilots in a particular year, $P_j(t)$, by hiring new pilots, the basic decision variable facing the management is the number of new pilots to be hired in time period t, $h(t)$. Therefore, a set of equations should be developed for the manpower system in Pilot Training Process (PTP) that captures the relationship between new hires, $h(t)$ and numbers of pilots, $P_j(t)$ over time.

As mentioned before, there are seven stages in the pilot supply chain. From the beginning of the Undergraduate Pilot Training until becoming an Instructor Pilot, the pilot must undergo approximately seven years of training and upgrading. This time delay makes the relationship between $h(t)$ and $P_j(t)$ even more important in nature. There are two other factors which add more complexity to this relationship. First, the promotion of the pilots in the progression over time to higher levels, and second, the common phenomenon of attrition and turnover among pilots.

The human resources practices for F-16 pilots can be summarized as follows:

- There are seven levels of pilots, with level 7 the most experienced
- Only new pilots can be hired in the beginning of each year
- The pilots are promoted to the next higher level from one time period to the next with a promotion rate of β_j
- Expected attrition rate is δ_j among the pilots at the end of the year
- Hiring of pilots takes place only at the beginning of a time period and attrition takes place only at the end of a time period. Hence, the numbers of pilots remain constant during a time period

The stocks and flows of the manpower system described above are depicted in Figure 3.

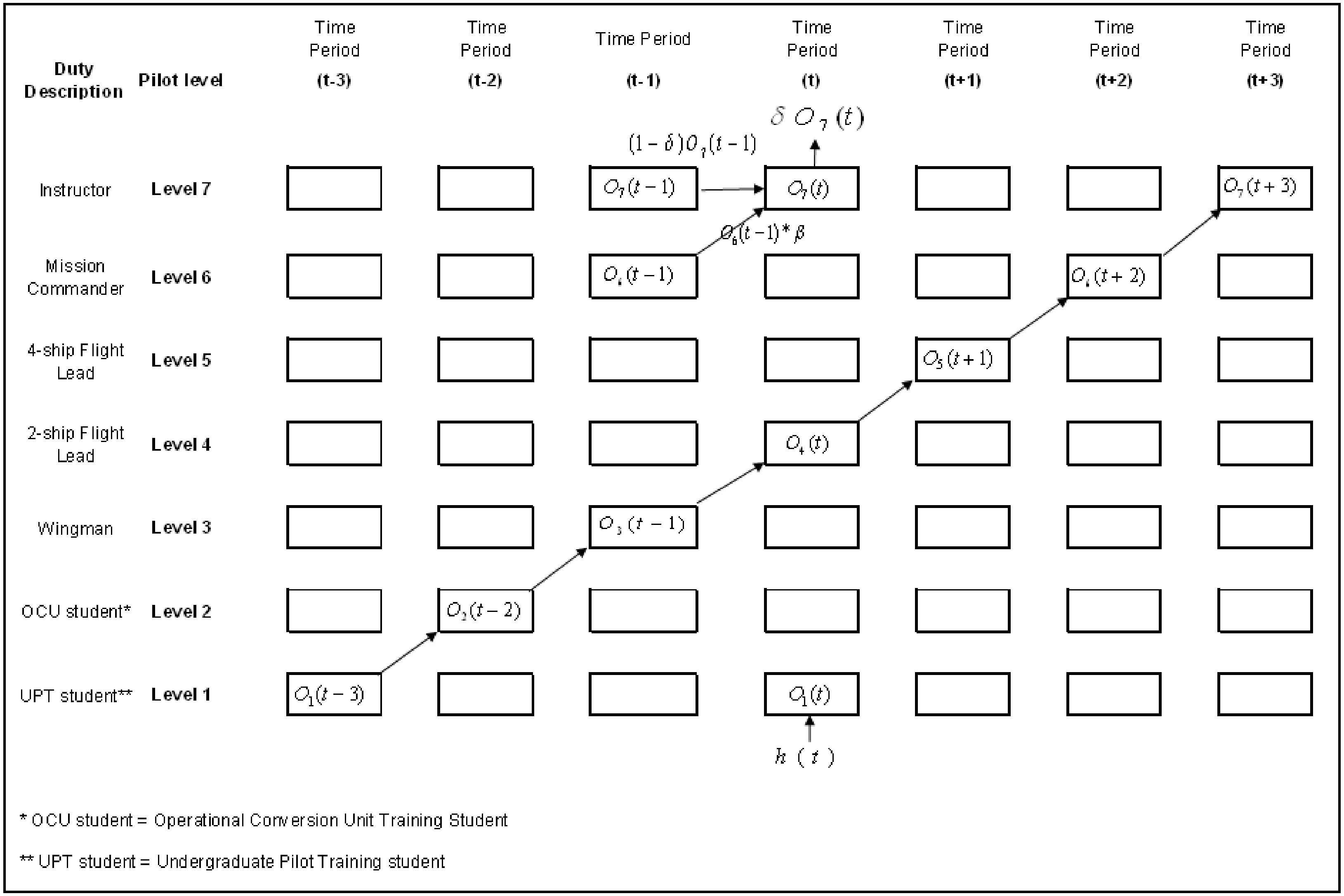

Figure 3. The stocks and flows of the manpower system in the F-16 Pilot Training Supply Chain.

The arrows in Figure 3 depict the flow of pilots through different steps in the pilot training supply chain. At the beginning of each year, a certain number of new hires, *h(t)*, enter the supply chain starting from level 1. At the end of each year, a percentage, δ_j, of pilots leave the squadron as a result of attrition or turnover. The remaining pilots are either promoted to a higher level or continue at the same level for the next year.

A. OBJECTIVE FUNCTION

The objective function in this optimization model will be formulated to minimize the total cost of achieving a desired number of seven different types of trained pilots for a seven-year time period. The total cost for the seven-year period is composed of two different costs. First is the cost of training. As described in Chapter II, in order to achieve the maximum level of readiness and preserve the CMR status, the pilots on hand have to fly a certain amount of sorties each year. Therefore, the training cost will be equal to the number of flying hours flown by the pilots during each year in total, multiplied by the cost of a flying hour.

The second cost in the objective function is the cost of carrying the inventory of pilots. Each pilot carried in the inventory costs the Air Force a composite rate. Therefore, the inventory carrying cost will be equal to the numbers of pilots of different types, multiplied by the composite rates. Hence, the objective function of this model is:

Minimize the total cost of readiness for the next seven-year period.

Min Training Cost + Inventory Carrying Cost

$$\min \sum_{t=1}^{7} HOURS(t) * C_{FH}(t) + \sum_{j=1}^{7}\sum_{t=1}^{7} C_j(t) * P_j(t), \quad \text{for } t = 1, 2, \ldots, 7$$

where C_{FH} =

	Years						
	1	**2**	**3**	**4**	**5**	**6**	**7**
C_{FH}	\$5,200	\$5,460	\$5,733	\$6,020	\$6,321	\$6,637	\$6,968

and $C_j(t)$=

	Years						
Pilot Levels	**1**	**2**	**3**	**4**	**5**	**6**	**7**
UPT student	$80,000	$84,000	$88,200	$92,610	$97,241	$102,103	$107,208
OCU student	$85,000	$89,250	$93,713	$98,398	$103,318	$108,484	$113,908
Wingman	$100,000	$105,000	$110,250	$115,763	$121,551	$127,628	$134,010
2-ship FL	$105,000	$110,250	$115,763	$121,551	$127,628	$134,010	$140,710
4-ship FL	$110,000	$115,500	$121,275	$127,339	$133,706	$140,391	$147,411
MC	$125,000	$131,250	$137,813	$144,703	$151,938	$159,535	$167,512
IP	$130,000	$136,500	$143,325	$150,491	$158,016	$165,917	$174,212

The objective function is then:

Min $5200*HOURS(1) + $5460*HOURS(2) + $5733*HOURS(3) + $6020*HOURS(4) + $6321*HOURS(5) + $6637*HOURS(6) + $6968*HOURS(7) + $80000*$P_1$(1) + $84000*$P_1$(2) + $88200*$P_1$(3) + $92610*$P_1$(4) + $97241*$P_1$(5) + $102103*$P_1$(6) + $107208*$P_1$(7) + $85000*$P_2$(1) + $89250*$P_2$(2) + $93713*$P_2$(3) + $98398*$P_2$(4) + $103318*$P_2$(5) + $108484*$P_2$(6) + $113908*$P_2$(6) + $100000*$P_3$(1) + $105000*$P_3$(2) + $110250*$P_3$(3) + $115763*$P_3$(4) + $121551*$P_3$(5) + $127628*$P_3$(6) + $134010*$P_3$(7) + $105000*$P_4$(1) + $110250*$P_4$(2) + $115763*$P_4$(3) + $121551*$P_4$(4) + $127628*$P_4$(5) + $134010*$P_4$(6) + $140710*$P_4$(7) + $110000*$P_5$(1) + $115500*$P_5$(2) + $121275*$P_5$(3) + $127339*$P_5$(4) + $133706*$P_5$(5) + $140391*$P_5$(6) + $147411*$P_5$(7) + $125000*$P_6$(1) + $131250*$P_6$(2) + $137813*$P_6$(3) + $144703*$P_6$(4) + $151938*$P_6$(5) + $159535*$P_6$(6) + $167512*$P_6$(7) + $130000*$P_7$(1) + $136500*$P_7$(2) + $143325*$P_7$(3) + $150491*$P_7$(4) + $158016*$P_7$(5) + $165917*$P_7$(6) +$174212*P_7(7)

B. DECISION VARIABLES

h (t) : Number of pilots being hired in time period *t*

$P_j(t)$: The observed number of pilots of level *j* in time period *t*

$InvP_j(t)$: The inventory of pilots of level *j* left after attrition at the end of time period *t*

HOURS(t) : Total flying hours flown by all levels of pilots in time period t

C. CONSTRAINTS

1. Level 1 pilots are solely made up of newly hired inexperienced pilots. Hence,

$P_1(t) = h(t)$, for t = 1, 2, …, 7……………………………………………………...(1)

2. Level 2, 3, 4, 5, 6 and 7 pilots in time period 1 are equal to a predefined starting inventory. Hence,

$P_j(t) = SI_j$, for j = 2, 3,… 7 and t = 2, 3, …, 7………………………………….....(2)

3. At the end of each year, some of the pilots either leave the Air Force or are assigned to a different squadron with an attrition and turnover rate of δ_j. Hence,

$InvP_j(t) = P_j(t) * (1-\delta_j)$, for j = 1,2… 7 and t = 1, 2, …, 7…………………...(3)

4. Conceptually there are two types of pilots at levels 2, 3, …, 7:

a) A fraction of pilots from a lower level in time period (t – 1) who are promoted to a higher level with a promotion rate of β, in time period t, and

b) Those that were at the same level in time period (t – 1) but have not been promoted to a higher level and therefore continue at the same level. Hence,

$$O_j(t) = \beta_{j-1} * InvP_{j-1}(t-1) + (1-\delta_j) * InvP_j(t-1),$$

for j = 2, 3,… 7 and t = 2, 3, …, 7 ……………....(4)

5. In order to be considered ready, there needs to be an effective number of pilots of each level at the end of time period t in each operational squadron, regarding the level of threat expected. More pilots are needed when risk level is high, less are needed when risk level is low.

$InvP_j(t) \geq REQ_j(t)$, for t = 1, 2, …, 7………………………………………….(5)

6. In case of a sudden drop in the expected threat level from very high to very low, there will be a certain level of excess inventory. In order to eliminate this over stock as quickly as possible, the model may not hire any new pilots for several years. However, this is not a desired situation for the continuity of the pilot flow in the system. Therefore, to provide a smooth flow of pilots and to avoid a gap in the continuous flow of pilots through the supply chain, a constraint of minimum number of pilots is set. In this way, it is assured that every year there will be a minimum number of pilots of each level in every time period t.

$InvP_j(t) \geq MIN_j(t)$, for t = 1, 2, …, 7…………………………………………..(6)

7. As described in Chapter II, in order to be considered as mission ready and in order to preserve the CMR status, each pilot in the operational squadrons must fly at least 260 flight hours per year. The level 1 students (UPT students) also need to fly 50 hours per year and level 2 students must fly 80 hours per year in order to proceed to the next step in the pilot training supply chain. This is the quality constraint for the model. If this constraint is met, then all of the pilots are assumed to be CMR for that particular year t.

$HOURS(t) \geq 50 * P_1(t) + 80 * P_2(t) + \sum_{j=3}^{7} 260 * P_j(t)$, for t = 1, 2, …, 7………...(7)

8. As described in Chapter II, each instructor can fly at most 433.3 flying hours per year. He spends majority of this time for training and supervising the wingman, 2-ship flight leads and 4-ship flight leads in his squadron. Therefore, this is the most critical capacity constraint of training which determines the maximum hours that can be flown in a squadron.

$MAX_{ins}(t) = 433.3 * P_7(t)$, for t = 1, 2, …, 7…………………………………...(A)

As described in Chapter II, 17% of all flights (44.2 flying hours per pilot) flown by the wingman, 2-ship flight leads and 4-ship flight leads in a squadron each year, must be fulfilled under the supervision of the Instructor Pilots. Instructor Pilots supervise the inexperienced pilots and they also evaluate their performances during the flights in order to decide who will be promoted to a higher level.

$\sum_{t=1}^{7} 0.17 * HOURS(t) \leq MAX_{ins}(t)$, for t = 1, 2, …, 7…………………………...(B)

When we rewrite the formulas A and B together; we get:

$44.2 * P_3(t) + 44.2 * P_4(t) + 44.2 * P_5(t) \leq 433.3 * P_7(t)$, for t = 1, 2, …, 7……...(8)

The set of equations (1) − (8) characterizes the multi-period manpower system for the pilots.

Although the numbers of aircraft and the total flying hours that the aircraft can fly is another critical constraint in the pilot training process, it was excluded from the scope of this study. The main reason for that is the fact that the capacity of the aircraft is much higher than the capacity of the instructor pilots. Therefore, adding another constraint which has no binding effect on the solution would be of no use. We also consider that the money spent on the aircraft is sunk cost and sunk cost does not change among different scenarios in the short run. The decision to buy new aircraft or decommission them is a very long term strategic decision and it is not possible to procure or decommission aircraft annually as a result of yearly threat level changes. Therefore, the calculation of the right number of aircraft in a squadron is outside the scope of this study and it is assumed that there are enough aircraft in the squadron for the adequate training of the pilots.

D. MODELING IN MICROSOFT EXCEL

A workbook was developed by using Microsoft Excel to develop the optimization model. The workbook has three sheets: 1) Inputs-Outputs, 2) Tables, and 3) Optimization Model. Each sheet is described in detail below.

1. "Inputs-Outputs" Sheet

The decision maker enters two inputs into the model: 1) the numbers of required pilots of each level for the next seven years and 2) the inventory of pilots of each type who are currently on hand. The required numbers of pilots of each level can be entered into the model by using the inputs table. The model does not calculate the pilot requirements, since it is a very high level decision which is given by the high-rank, strategic level officers. The pilot requirements are assumed to be related to the expected threat level in the future.

The on-hand pilot inventory is another important input to the system. The first level pilots are equal to the newly hired students in the first year, while the stock level of other pilot types is a result of decisions given in previous years. These numbers are transferred into the optimization model automatically by the hyperlinks developed. Figure 4 depicts a snapshot of the input tables used in the optimization model.

D	E	F	G	H	I	J	K	L	M	N
INPUTS									Starting Inventory	
Required # of Pilots of Each Level Based on Threat Level										
	Years								Pilot Levels	Inv
Pilot Levels	1	2	3	4	5	6	7		OCU Student	5
Wingman	4	5	4	6	7	5	6		Wingman	6
2-ship FL	5	6	4	6	6	6	5		2-ship FL	4
4-ship FL	3	5	3	5	4	4	3		4-ship FL	3
Mission Comm.	3	4	3	3	4	5	4		Mission Comm.	3
Instructor	2	3	3	2	2	4	2		Instructor	2

Figure 4. Input tables of the Inputs-Outputs sheet.

The second part of the Inputs-Outputs sheet is the outputs table. Once the model is run and optimal solution is found, the results are automatically copied to the results table by the model. The results table shows the following data: how many new pilots must be hired in the next seven years, the numbers of pilots of each type in the squadrons at the end of each year, the total flying hours that must be flown and the total training cost for the next seven years. Figure 5 depicts a snapshot of the outputs of a scenario solved by the optimization model.

OUTPUTS								
	Ending Inventory of Pilots at the end of each year							
	Years							
Pilot Levels	1	2	3	4	5	6	7	
New hires	14.65	10.81	10.98	11.07	8.97	2.22	2.22	
UPT students	13.18	9.73	9.89	9.96	8.08	2.00	2.00	
OCU students	10.80	11.76	8.85	8.85	8.91	7.31	2.04	
Wingman	10.80	10.21	10.97	8.55	8.34	8.37	7.00	
2-ship FL	10.20	9.13	8.58	9.12	7.32	7.00	7.00	
4-ship FL	6.30	7.53	7.07	6.64	6.91	5.82	5.43	
Mission Comm.	6.30	5.51	5.88	5.77	5.51	5.56	5.00	
Instructor	2.63	3.12	3.02	3.12	3.11	3.02	3.00	Total Cost
Flight Hours	13587.27	13330.50	13063.39	12370.10	11655.76	10665.97	9443.49	$49,130,137.78

Figure 5. Output table of the Inputs-Outputs sheet.

2. “Tables” Sheet

The “Tables” Sheet includes the pre-determined data tables which are used by the optimization model. The data in this sheet are:

- flying hour costs
- composite costs of the pilots
- attrition and turnover rates
- promotion rates
- minimum numbers of pilots of each level required
- required numbers of pilots of each level required (copied automatically from the Inputs-Outputs sheet)

3. “Optimization Model” Sheet

The optimization model is developed on this sheet. It is a multi-period linear programming model which has 112 variables and 210 constraints. Due to the big size of the model, the regular “Solver” installed in Microsoft Excel is not capable of running the model. In order to run the model, a more advanced version of the solver is required. The Premium Solver version 7.1 developed by the Frontline Systems, Inc. can be used to run and solve this model.

Each decision variable and each constraint is explained briefly to help better understanding of the equations. It is easy to make any adjustments to the model. More constraints and decision variables can be added into the model in the future, if necessary. If no modification is required then the user can call the solver and run the model. All the inputs entered previously are used by the model and the results are copied back to the results table in the first sheet.

Figure 6 provides a snapshot of a part of the optimization model. The decision variables, objective function, and constraints are defined on separate rows with a brief description.

	A	B	C	D	E	F	DJ	DK	DL	DM
1										
2			New Hires Each							
3			h(1)	h(2)	h(3)	h(4)	HOURS(7)			
4			New hires in year 1	New hires in year 2	New hires in year 3	New hires in year 4	Hours flown by pilots in year 7			
5		Decision Variables	5	6	5	5	7663.1579			
6		Objective Function					$6,968	$36,878,422.35		
7		Constraints								
8		UPT in year 1 = New hires in year 1	-1					0	=	0
9		UPT in year 2 = New hires in year 2		-1				0	=	0
10		UPT in year 3 = New hires in year 3			-1			0	=	0
11		UPT in year 4 = New hires in year 4				-1		0	=	0
12		UPT in year 5 = New hires in year 5						0	=	0
13		UPT in year 6 = New hires in year 6						0	=	0
14		UPT in year 7 = New hires in year 7						0	=	0
15		InvP1(1) = PT1(1) * (1-Attrition rate)						0	=	0
16		InvP1(2) = PT1(2) * (1-Attrition rate)						0	=	0
17		InvP1(3) = PT1(3) * (1-Attrition rate)						0	=	0
18		InvP1(4) = PT1(4) * (1-Attrition rate)						0	=	0
19		InvP1(5) = PT1(5) * (1-Attrition rate)						0	=	0
20		InvP1(6) = PT1(6) * (1-Attrition rate)						0	=	0
21		InvP1(7) = PT1(7) * (1-Attrition rate)						4.44089E-16	=	0
22		OCU in year 1 = Starting inventory in year 1						9	=	9
23		OCU in year 2 = [InvP1(1)*(Pro. rate)] + [InvP2(1)(1-Pro rate)]						8.88178E-16	=	0
24		OCU in year 3 = [InvP1(2)*(Pro. rate)] + [InvP2(2)(1-Pro rate)]						0	=	0
25		OCU in year 4 = [InvP1(3)*(Pro. rate)] + [InvP2(3)(1-Pro rate)]						0	=	0
26		OCU in year 5 = [InvP1(4)*(Pro. rate)] + [InvP2(4)(1-Pro rate)]						-8.88178E-16	=	0
27		OCU in year 6 = [InvP1(5)*(Pro. rate)] + [InvP2(5)(1-Pro rate)]						1.77636E-15	=	0
28		OCU in year 7 = [InvP1(6)*(Pro. rate)] + [InvP2(6)(1-Pro rate)]						8.88178E-16	=	0

Inputs-Outputs / Tables / **Optimization Model**

Figure 6. Optimization Model sheet.

E. SIMULATION SPECIFICATIONS

1. Hardware

The simulation was run by using a Dell desktop computer which has an Intel Pentium IV 2.80 GHz microprocessor and 1 GB of RAM.

2. Software

Microsoft Office Excel 2003, with the Premium Solver version 7.1 software package installed, was used for running the simulation. Microsoft Windows XP Home Edition operating system was installed in the PC.

3. Elapsed Time

By using the hardware and software described above, running each scenario took an average of 12 seconds. Thus, running the whole simulation with 1000 scenarios required approximately 3 hrs 20 min in total. However, running the whole simulation at once was not practical due to the capacity limitations of the system. For example, the computer gave a run time error when the file sizes got relatively large. Therefore, the simulation was run in 10 batches with 100 scenarios in each batch. A more powerful computer with a higher storage and micro-processing capacity can be used in order to run the simulation all at once and in a shorter time period.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. COMPUTATIONAL EXPERIMENT AND RESULTS

This chapter provides the computational experiment and results. The simulation methodology, and information and tools used in the simulation are described. The results of the simulation are presented with charts and graphs at the end of this chapter.

A. SIMULATION METHODOLOGY

A "war game" approach is developed to best simulate the current real-world environment and to create different scenarios for use in analyzing the performance of a mathematical model. Such approach will enable us to analyze and measure the robustness of our model under different conditions and address the weaknesses if there are any. The results of our simulation will be used to give recommendations to the decision makers.

There are many different simulation software packages on the market, for either military or civilian purposes and with different levels of realism. The key issues determining the reality level of any simulation are: reliable data collection, selection of key characteristics and behaviors, the use of simplifying assumptions and validity of the possible outcomes.

Law and Kelton (2000) describe user friendly scenario creation tools developed within these commercial simulation packages for creating different scenarios. Each scenario can be created and every single variable can be simulated using these tools. Then the simulator uses these inputs and predefined scenarios to run the model many times. The technique used by the simulation packages for creating different scenarios is to create random numbers. Once random numbers are created, these numbers can be transformed into numbers based on a given probability distribution function. For defining the behavior pattern of a variable in a simulation, the users typically apply two methods:

1. Trying to predict the probability distribution function by analyzing the data collected from previous experiences

2. Defining any random probability distribution function to a variable if there is no information about the behavior of the variable

The second method is much easier and cheaper, but the results of such a simulation are very unlikely to represent a real situation. Therefore, the first approach is used in this study to develop a probability distribution function and past data is analyzed to define the pattern of the pilot requirements. If it had been possible to collect data of how many F-16 pilots were recruited each year in the past, the probability distribution function would have been improved. However, such data is confidential and thus hard to get. Hence, a different method is used to predict how many pilots may be needed in a particular year.

Knowing that there is a relationship between threat levels faced and the numbers of new hires every year, this project attempted to predict the threat levels to security rather than predicting the demand for pilots. When the threat level is high, such as in a war situation, more pilots are needed. Based on this assumption, it will be possible to simulate the demand curve for the F-16 pilots and test the performance of the mathematical model. The following steps are followed for simulation of the mathematical model:

1. Demand for F-16 pilots are defined under different threat levels

2. A probability distribution function of threat levels is created by analyzing the important events in American History since 1950

3. Arena 10.0 simulation software package by Rockwell Company is used to create 1000 different random threat-level scenarios which are based on the probability distribution function

4. An Excel workbook is developed to run the mathematical model many times

5. The results of the simulation are recorded and interpreted

1. Demand for F-16 Pilots under Different Threat Levels

It is assumed that there are three different threat levels that the U.S. can face in any particular year: red, orange and white, with red being the highest threat level. The threat level is increased to red when the country is in a war situation. When the threat level is orange the country is in a major crisis, with “crisis” defined as the existence of a certain level of possibility of war in the near future. White threat level is assumed to be a very peaceful period when no threat is expected in that year or in the near future.

Based on these three threat levels, it is assumed that a fixed number of different levels of F-16 pilots are needed every year. The assumed demand for F-16 pilots under different threat levels are shown in Table 4.

Table 4. Demand for F-16 pilots under different threat levels

Pilot Level / Threat Level	White	Orange	Red
Wingman	5	6	7
2-FL	5	6	7
4-FL	4	4.5	5
MC	4	4.5	5
IP	2	2.5	3

2. Historical Data Approach

Once the relation between threat levels and the demand for F-16 pilots is set, the important events in American history since 1950 are analyzed to predict the probability distribution function of threat levels. In order to do that, each year is coded with a white, orange, or red color. The important events and color codes are shown in Figure 6. The fact that there was always a certain level of tension between the U.S. and the U.S.S.R until the 1990s is ignored in the analysis. In the 58 years since 1950, the threat level has been red for 30 years, orange for 17 years, and white for 11 years. These values will be used in the next step to determine the probability distribution function for the threat levels.

The color-coded Figure 7 depicts the results of the timeline of conflicts in U.S. history since 1950. Important events that happened in any particular year are also shown in the figure for each year.

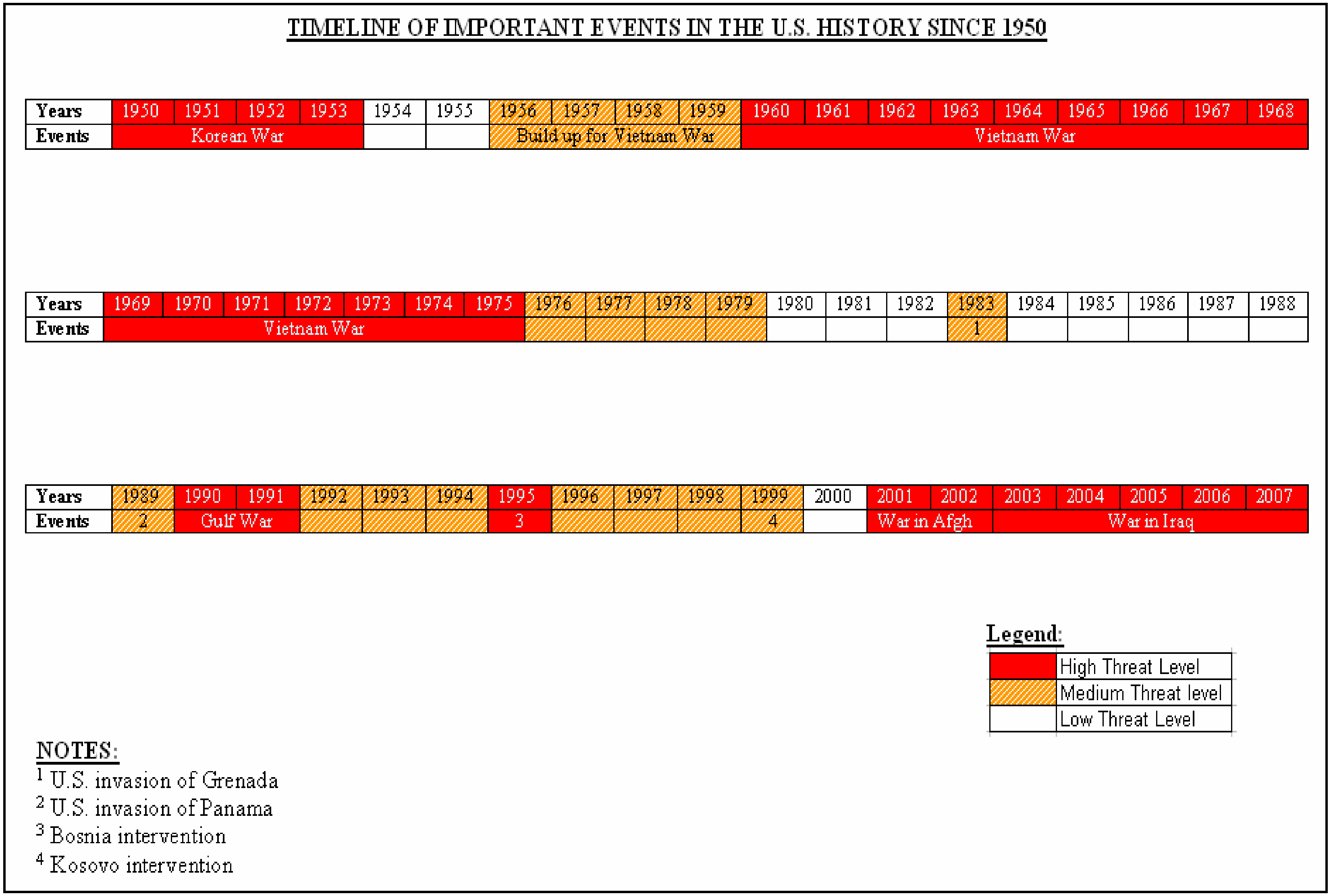

Figure 7. Color coding of the timeline of U.S. history since 1950

3. Analysis with Input Analyzer

The Input Analyzer is a standard component of the Arena simulation software package. This tool can be used to fit a probability distribution function to any given input data. The Input Analyzer can also be used for generating random sets of data out of certain probability distribution functions. The tool measures how all of the possible distribution functions fit the given input data and summarizes its findings both visually and mathematically.

In order to use this tool, the historical data are converted into numerical inputs where white is converted into 1, orange is converted into 2, and red is converted into 3. These numbers are recorded in a text (.txt) file in sequence and imported into the Input Analyzer. Then, by using the "Fit All" function, all of the possible distributions are fitted to the input data and the best fit is displayed to the user. According to the analysis of the Input Analyzer, the probability distribution function for the threat levels is 0.5 + 3 * BETA (1.53, 0.982).

The summary of the analysis of historical input data is presented in Figure 8.

Considering the fact that the government of the U.S. has declared a long-lasting war against global terrorism after the September 11 attacks in 2001, it is more likely to expect high threat levels in the years after 2007 compared to previous years. Therefore, the distribution function will be adjusted slightly to make it more realistic in the next step before creating the random scenarios.

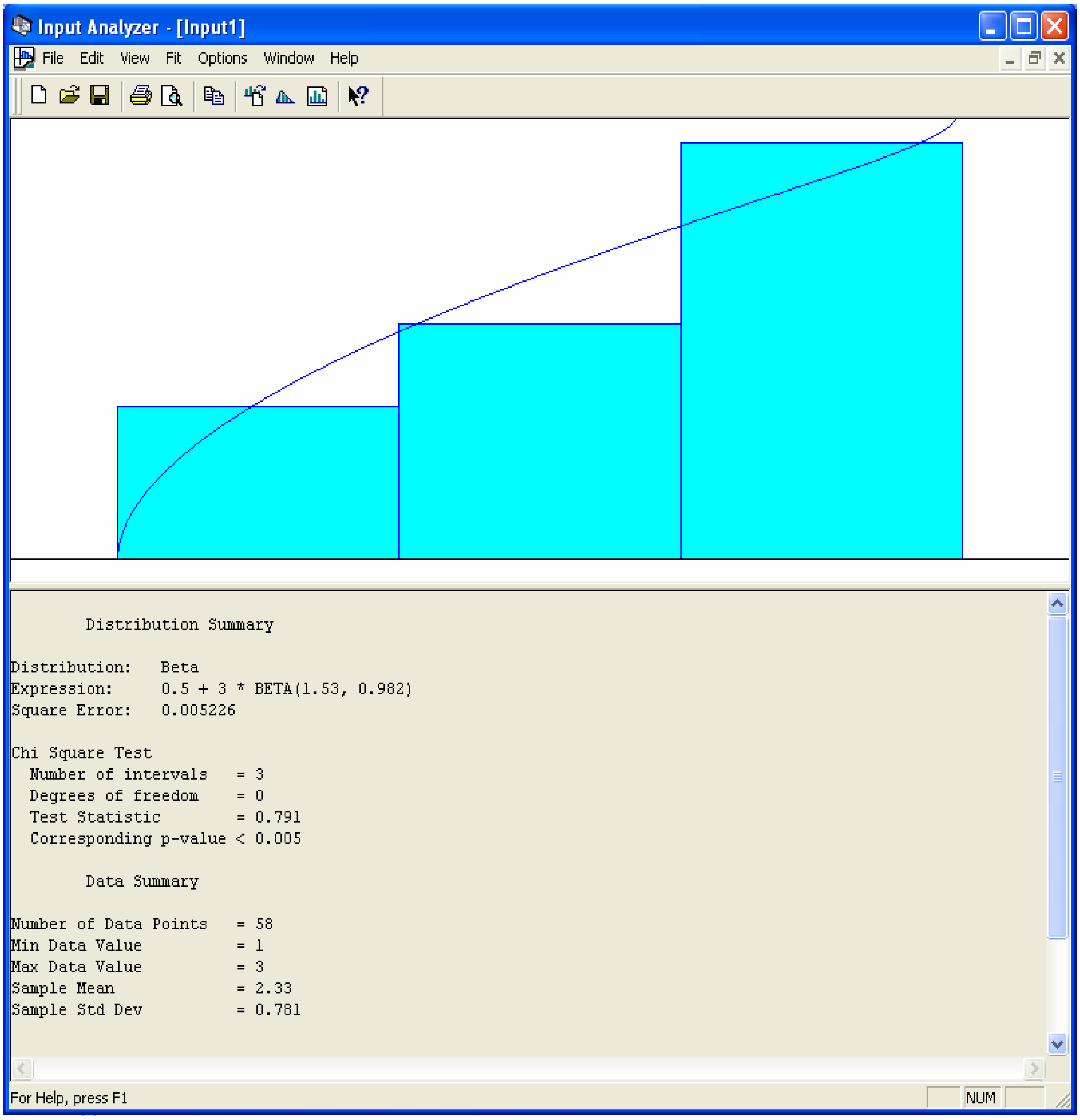

Figure 8. Distribution summary of the historical input data

4. Generating Random Scenarios Using Input Analyzer

By using the “Generate New” function of the Input Analyzer, new scenarios can be created which fit any of the probability distribution functions given. It is possible to make adjustments in the parameters of the distributions, if necessary. The eleven different distribution functions by which random numbers can be generated can be seen in Figure 9.

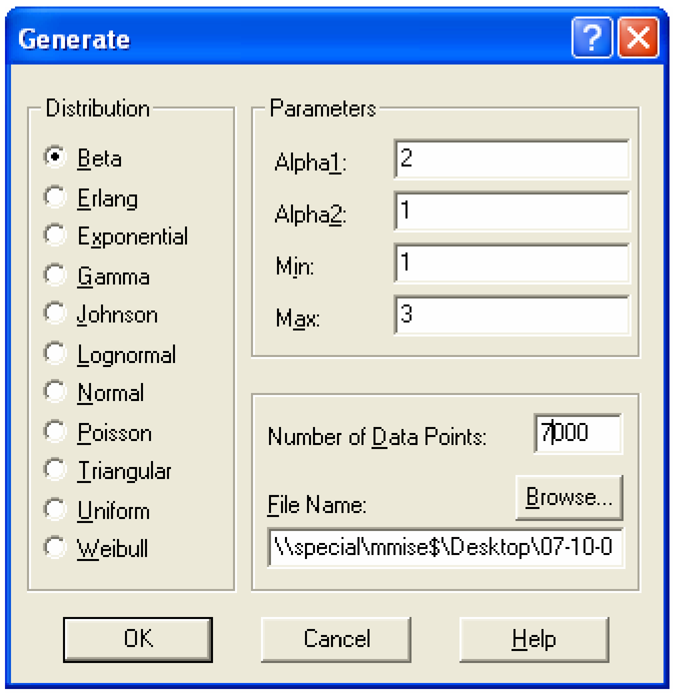

Figure 9. New scenario generation tool

While creating new scenarios, the results of the input analysis are used as a starting point and the probability distribution function is set to Beta Distribution, but Alpha value is increased to 2.5 and Beta value is decreased to 0.75. In this way, a steeper distribution is achieved which provides higher possibilities of high threat level scenarios to be created. It is required to create 7000 random numbers as there are seven years in each scenario and 1000 different scenarios to get. Once the numbers are created, these random numbers are rounded to the closest integer value to get integer results of 1, 2, or 3.

Table 5. A sample of newly created random scenarios

	Expected Threat Levels						
Scenarios	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
1	2	3	2	2	2	3	2
2	3	3	3	3	2	1	3
3	2	2	3	3	3	1	2
4	3	2	2	2	3	2	1
5	2	2	1	3	2	2	2

As described in Chapter III, the optimization model solves the hiring problem for a seven-year period. If there are three different threat scenarios that are likely to occur in each year, then there are $3^7 = 2187$ different possible scenarios that can be created for the seven-year time periods. Generating 1000 different scenarios with the Input Analyzer therefore provides a very good coverage for simulating possible outcomes. The summarized histogram of the newly created random scenarios can be seen in Figure 10.

B. RUNNING THE SIMULATION

The next step is to run the optimization model multiple times using the random scenarios created by Input Analyzer. Due to the great numbers of scenarios created, it would be impractical to run the model manually for 1000 times. Instead, a new tool is developed which will run the model automatically and record the results for further analysis.

A new worksheet called “User File” is created by using Microsoft Excel with a set of macros. It is practical to automate a task by using macros if the task is to be performed repeatedly in Microsoft Excel. A macro is a series of commands and functions that are developed by using Microsoft Visual Basic modules and can be run whenever it is needed to perform the task.

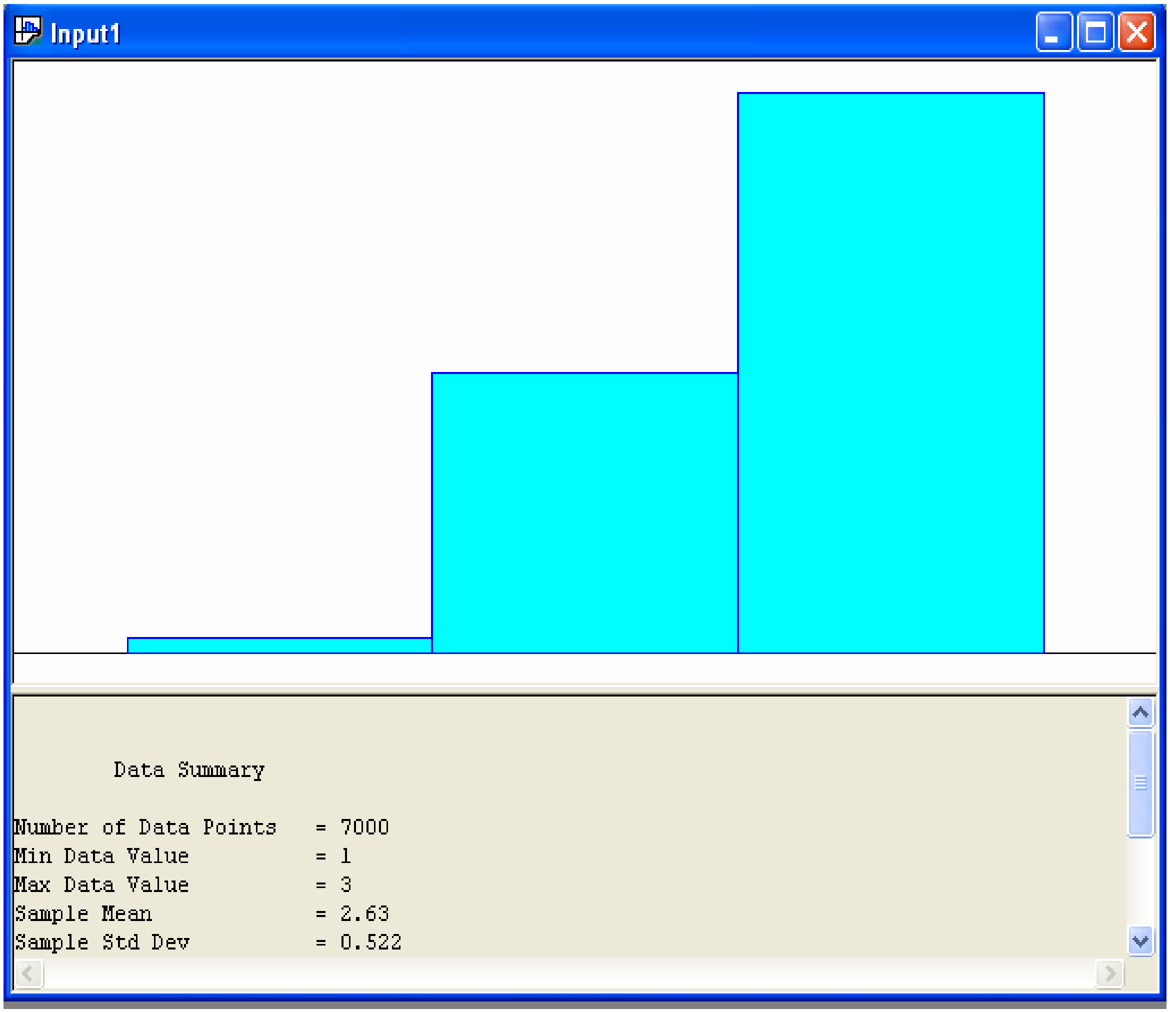

Figure 10. Data summary of newly created scenarios

The macro developed for running the optimization model is basically composed of three different steps:

- The inputs are copied from the user file into the optimization model in the first step
- Premium solver is called automatically in the optimization model worksheet by the macro and the linear model is solved in the second step
- The results of the solution are copied from the optimization model into the user file and recorded in the third step

These steps are repeated for each of the 1000 scenarios created.

The user file worksheet is a powerful tool that helps the user to test the optimization model easily whenever the parameters are changed. While it saves the user a lot of time by doing the copying and pasting processes automatically, it also provides the necessary calculations and analysis of the inputs and outputs quickly. The user file worksheet is composed of three sheets:

- “Inputs sheet”
- “Outputs sheet”
- “Tables & Charts sheet”

The Inputs sheet contains the inputs of the random scenarios created, which are numbers of pilots of each level required in scenario and the starting inventories of pilots. The Outputs sheet stores the values for the numbers of hires in each year, the numbers of pilots remaining on hand at the end of each year after attrition, the numbers of flight hours that must be flown each year, and the total cost of each scenario. The Tables & Charts sheet contains the visual graphs and analysis tools for the interpretation of the results.

C. RESULTS

1. Total Training Costs

The first finding of this study is about the total cost of training. The minimum cost of training is calculated as approximately $42.75 million while the highest cost of training is calculated as $50.47 million per squadron for a seven-year period. The mean value for the training cost is $47.92 million with a standard deviation of $1.62 million. The results of all scenarios are plotted on the scatter diagram in Figure 11. As the majority of the scenarios involve a high risk environment, most of the results are clustered around the upper segment of the diagram.

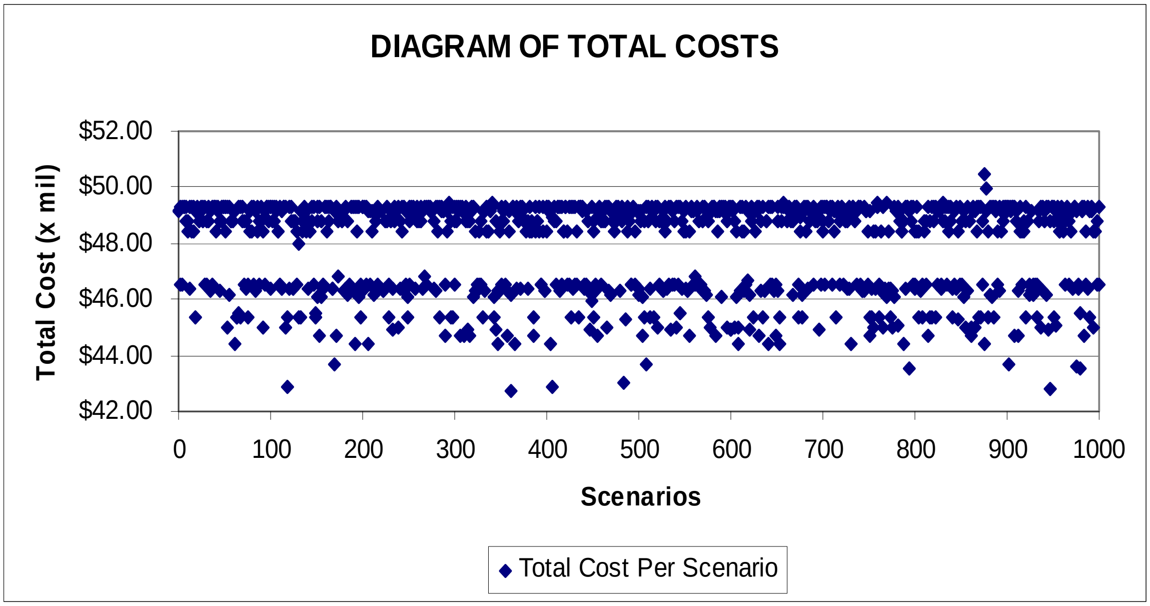

Figure 11. Scatter diagram of total training costs

The economical law of diminishing marginal utility is observed in the findings of this study. The incremental percentage of scenarios that can be covered by each extra dollar spent is diminished as the total money spent is increased. Figure 12 shows the percentage of scenarios covered with each dollar spent on training. The figure also presents the decision makers with the trade-off between cost and readiness. The decision makers know how much money is necessary to be ready for every possible scenario and how much this readiness level drops when there is a cut in the training budget.

There are some jumps at the total training costs, indicating discontinuities in the results of the scenarios. These discontinues are due to the limitation of simulation methodology with a relatively small number of trials. Had the simulation involved a very large number of trials, the data would line up to form a smooth curve.

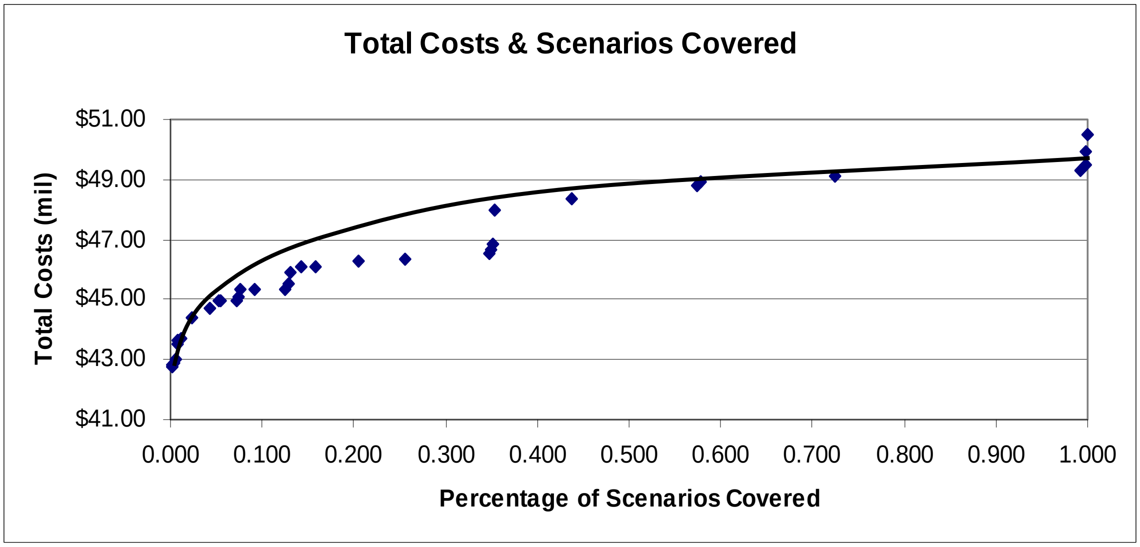

Figure 12. Diminishing marginal utilities in total pilot training costs

2. Impact of Planning Horizon Length on the Number of Pilots

There are basically two different values which define the required number of pilots of each type at the end of the years. The first value is termed "Myopic Levels" and represents the required number of pilots based on the current threat level in each particular year. Myopic levels of required pilot numbers define the annual pilot requirements and disregard the requirements in the future years. The second value is the results of the optimization model, called the "Long-Term Levels," which takes into account not only the current threat level but also the threat levels over the horizon.

The results of this study show that a certain level of excess inventory of pilots must be carried in order to be ready in the long run. Short-term planning does not provide 100% readiness levels over time, and a maximum level of readiness is possible only if the threat levels in the long run are taken into account. Figure 13 shows the difference between the myopic and the long-term levels for the number of pilots. It can be seen in the figure that the long-term levels of pilots are higher than the myopic levels. There are several reasons for this excess inventory:

a) A certain “safety stock” number of pilots must be carried in order to achieve maximum readiness levels for all of the years in a seven-year period. When the threat level drops for a short period of time, the model tends to keep the pilots in order to achieve the required readiness levels in the future years. It is one of the objectives of the study that the Air Force is ready to serve whenever needed. This fact points out the importance of anticipatory planning. If hiring plans are made for shorter periods of time then it will not be possible to keep the readiness levels at maximum in the latter periods.

b) It is also a necessity to keep a certain level of excess pilots due to the limitations of hiring and firing pilots. It is not possible to fire the pilots for a short period of time and re-hire them when the threat level increases. Once the pilots are removed from the system, the only way to replace them is to train new ones from the very beginning of the supply chain. Therefore, it is less costly for the Air Force to keep the excess pilots on hand even though the threat level has dropped temporarily.

c) The attrition, turnover, and promotion rate numbers are hypothetical and rounded numbers. They are kept the same for the entire simulation. In real life, these numbers are also random and change every year. The decision makers also have the chance to change these numbers from year to year, if necessary. However, it was not possible to reflect these real life aspects in the model with the data acquired and with the complexity level of this study. In general, these numbers also have a significant effect on the inventory levels.

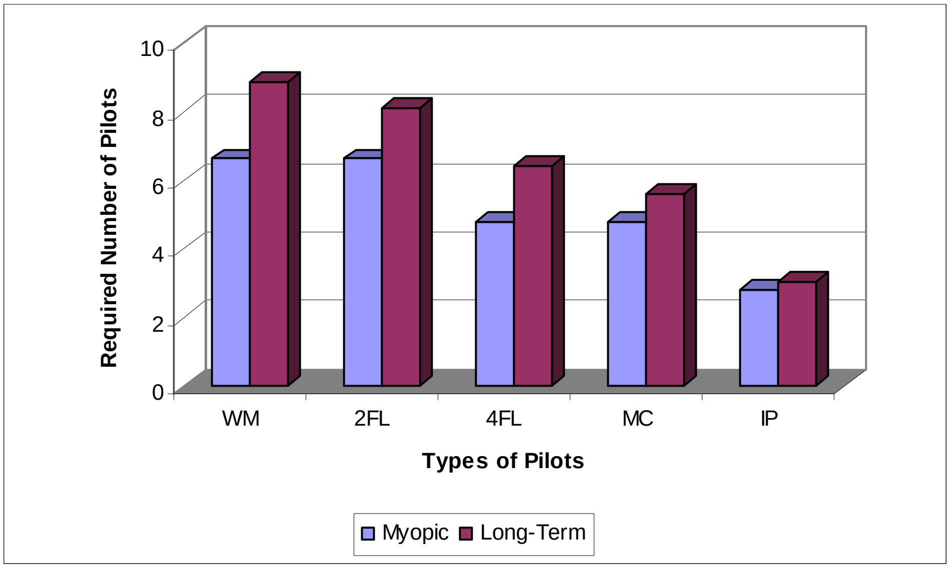

Figure 13. Comparison of myopic and long-term pilot inventory levels

3. Importance of Starting Inventory

The size of the on hand inventory is a very important factor that affects the number of pilots on hand and the total training cost. If an excessive number of pilots are hired in the preceding years in the supply chain, then in the short run it is not easy to eliminate this excess inventory in the latter stages.

In order to get feasible solutions from the model during the simulation, the starting inventory levels were kept relatively high. However, the model could not easily get rid of this excess inventory with the defined attrition and turnover rates. This is similar to the situation in real life. Once a pilot is hired, that pilot has to be carried in the inventory for multiple years. Remembering that the annual cost of a single pilot is approximately $1.4 million, the initial hiring plans must be made very carefully every year in order to avoid excessive pilot inventories. Figures 14 and 15 show the required number of pilots in the first four years and in the last three years of the supply chain. The average long-term pilot levels are higher than the myopic levels in both of the figures but the long-term pilot levels are significantly lower in the last three years compared to the long-term pilot levels in the first four years of each scenario. This is mainly because of the fact that elimination of the excessive starting inventory takes multiple years.

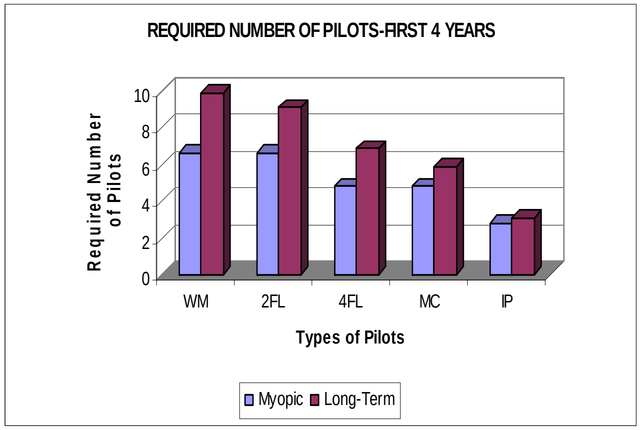

Figure 14. Average required number of pilots in the first four years of each scenario

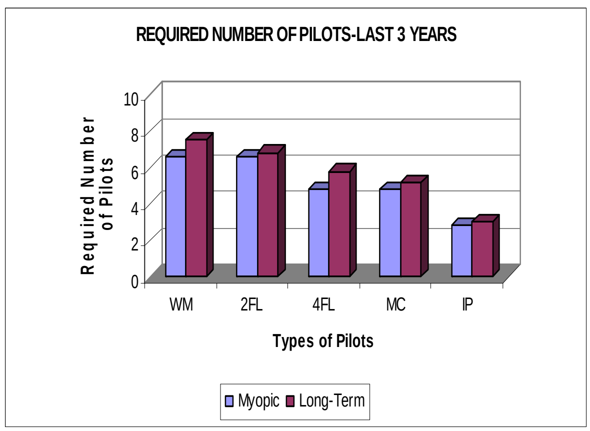

Figure 15. Average required number of pilots in the last three years of each scenario

4. Cost of Attrition and Turnover

Attrition and turnover is another cost increasing factor in pilot training. On average, a 1% increase in attrition and turnover rate, all else remaining equal, causes a 2.26% increase in total training costs. It must be one of the objectives of the Air Force to minimize attrition among jet pilots by targeting the main causes of attrition. Some of the causes for high attrition are: assignment of pilots to ground duties, the gap between private sector pay and military pay, family issues such as family separation, and job satisfaction.

Turnover of pilots (i.e., assignment of pilots to other squadrons) is another factor that increases total costs. Although not covered in this study, the cost of additional spin-up sorties is very high; hence, they should be minimized whenever possible. These sorties are mandatory for all pilots if the mission statement of the new squadron is different than that of the previous squadron. Another reason for the necessity to lower turnover rate is that it has a very high impact on the job satisfaction of the pilots. An assignment to a different squadron is a very big obstacle in the career of a jet pilot. Therefore, it is necessary for the Air Force to review and possibly revise its assignment policy, increase the duration of the tours, and consider the family status of the pilot prior to assignment to a different location. These arrangements will all have a positive effect on the job satisfaction of the pilots, and a decreasing effect on the total cost of training.

5. Length of the Pilot Training Progression

The length of the F-16 pilot training supply chain is another cost increasing factor. As the supply chain gets longer, the training costs get even higher and it becomes more difficult to make anticipatory planning of hiring. Since the readiness and experience levels of a pilot are most relevant to the numbers of sorties that he flies and irrelevant to the years of service, it is possible to decrease the length of the training progression. In queuing theory, Little's Law states that the average number of customers in a steady-state system is equal to their arrival rate multiplied by the average time they spend in the system ($N=\lambda*T$, where N is the average number of customers, λ is the customer arrival rate, and T is the average time customers spend in the system). Based on Little's Law, if the length of a process can be decreased, then the size of the Work in Process (WIP) inventory can also be decreased with the same proportion. This law is applicable to any process, including the F-16 pilot training progression.

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSIONS

The purpose of this study was to develop a model-based approach for generating an optimal training plan for F-16 pilots. The model developed is suitable for analysis and provides a good understanding of the pilot training progression, but it must be calibrated carefully before it is used for management purposes. The model shows that anticipatory planning of pilot training is essential for the training of pilots, as the training progression is very lengthy and complex. It is also essential because of the high cost of pilot training and the high cost of poor manpower planning.

In the first phase of the study, the steps in the pilot training progression were identified and the important aspects of the progression were defined. The pilot training progression was approached as a supply chain where the outputs of the latter stage were the inputs for the next stage. The attrition and turnover among the pilots and promotion of the pilots from one stage to another made this model complicated. There were also training and capacity constraints which needed to be considered while designing the model.

In the next step, the mathematical model of the pilot training supply chain was developed. All the key aspects of the training progression, which were defined in previous chapters, have been incorporated into the model as constraints. The problem was designed as a multi-period linear programming model. Such an approach provides for the flow of pilots from one stage to another over a certain time period. The user of the model would specify the numbers of pilots required for a seven-year period together with the numbers of different types of pilots who were currently on hand, and the model would calculate how many new pilots had to be hired each year. The model calculated the total cost of training for the maximum level of readiness. The model also gave how many pilots would be on hand at the end of every year.

Once the mathematical optimization model was designed, it was tested under different scenarios. For this purpose, 1000 random scenarios were created which were likely to occur in the future. The threat levels in the history of the U.S. were analyzed to define the probability distribution of the threat levels. The random scenarios for the future were then generated based on this probability distribution. In each scenario, different threat levels were generated randomly for each year and the pilot requirements of each scenario were specified according to these threat levels. In order to run the simulation automatically, a macro was designed in Microsoft Excel which ran the model multiple times and recorded the results on a different Excel sheet.

Finally, the results of the simulation were presented and interpreted. Recommendations for reducing the pilot training costs were given to the decision makers in the Air Force based on the findings of the study.

The Excel worksheets and models developed for this thesis are available from the writer and advisors, for future researches, upon request.

B. RECOMMENDATIONS

Based on the analysis and conclusions discussed earlier we recommend the following to the U.S. Air Force in order to reduce the pilot training costs but at the same time increase the readiness levels:

1) Anticipatory planning of manpower hiring, firing, and promotion decisions are essential in the long run. The length and complexity of the pilot training supply chain is the main reason for this recommendation. It is not possible to suitably address a sudden increase in threat level if we do not think about it well in advance and prepare for it.

2) A business modeling approach must be developed which considers the production/training limitations in the squadrons prior to hiring new pilots. An excessive number of pilots can be hired in a very short time, but it may not be possible to train these pilots in the operational squadrons if there are not enough Instructor Pilots (IP). The numbers of IPs that are currently on hand are the result of the planning decisions made at

least seven years ago. More pilots may be required to be hired and trained in the early stages so that the training capacity of the squadron is high enough in the latter stages.

3) The length of the pilot training supply chain must be shortened and simplified. It is a general business fact that it gets more difficult to make projections for the future as the planning horizon gets longer. The estimations of threat levels in the future years are more likely to be inaccurate, especially in the volatile environment of the 21st century. There is also more inefficiency in a system if the process is very lengthy. It gets even harder to identify the root causes of these inefficiencies in the system.

The amount of Work in Process (WIP) is directly proportional to the cycle time of the process. Similarly, if the cycle time of the pilot training system can be reduced, then it will be possible to reduce the total number of pilots.

4) Attrition and turnover are two very important cost increasing factors. The attrition and turnover rates must be reduced in order to reduce the training and costs and increase the readiness levels. Based on the literature reviews conducted at the beginning of this study, the following actions are recommended in order to decrease the attrition rate:

- Assigning the pilots to flying duties more than to the ground missions
- Increasing the pilot pay and benefits so that their pay rates become closer to the private sector pilots
- Considering the family ties and responsibilities of the pilots when reassignment is necessary and picking those pilots who are less likely to be affected by such an action
- Increasing the job satisfaction and motivation of the pilots

Turnover among pilots has additional cost increasing effects due to spin-up sortie requirements. The turnover rate can be decreased by:

- Developing a new assignment policy aiming to minimize the movement of pilots among squadrons
- If inevitable, moving pilots among squadrons which have similar mission statements
- Making hiring decisions which are based on the needs of each squadron specifically rather than making aggregate planning decisions for all squadrons

- Increasing the durations of the tours
- Considering the family situation of the pilot before an assignment and picking the pilots who are less likely to be affected from the move
- Compensating the gaps and losses in the pilot's career

C. SUGGESTIONS FOR FUTURE RESEARCH

The modeling approach and simulation method used in this study reveal a number of potential research topics that would benefit the Air Force and the DoD. These include the following:

- The research methodology of this study can be used for analyzing the supply chain for other pilot types, both in the Air Force and the Navy. The optimization model can be reconfigured in order to represent the different steps in these supply chains.
- The optimization model can be improved by adding more constraints. Skill acquisition, CMR vs. BMC pilot distinction, and sortie profiles are some examples of other constraints that need further analysis and addition into the model.
- The starting inventory levels were kept relatively high in order to get feasible solutions from the optimization model. Thus, the impact of starting inventory was very high in the results of the simulation. This impact can be minimized by using a rolling horizon approach. In a rolling horizon approach, the outputs of a preceding run are used as the inputs of the latter runs, eliminating the impact of initially assumed values.
- In this project it was not possible, due to classified data restrictions, to reach the exact values of the demand curve for different types of pilots. Therefore, an indirect approach was followed in this study to estimate the demand for pilots. However, a more realistic study can be conducted by using the exact historical manpower demand data for F-16 pilots.
- Fixed attrition and turnover rates were used throughout the entire simulation. In fact; these rates change continuously from year to year. Again, due to classified data restrictions, it was not possible to get real data for attrition and turnover. If these data can also be randomly simulated based on the historical data, the ability of simulation to represent the real life situation will be improved. The design of the simulation technique enables small changes to be made on the macro, so that it may be used for the same purpose.

LIST OF REFERENCES

Apte, Uday M. (2007). "Capacity Planning Model for Information-Intensive Services: Example of Insurance Claims Operation," Working Paper, Graduate School of Business and Public Policy, Naval Postgraduate School, Monterey, CA.

Avital, I. (2004), "Two-Period, Stochastic Supply-Chain Models With Recourse For Naval Surface Warfare," Master's Thesis, Department of Operations Research, Naval Postgraduate School, Monterey, CA.

Azimetli, M., 2nd Lieutenant, (2007, September 10). [Interview by Murat Mise].

Balakrishnan, A., Render, B., Stair, R. M., Managerial Decision Modeling with Spreadsheets, Pearson Prentice Hall, Upper Saddle River, New Jersey.

Bigelow, J., Taylor, W., Moore, S., Thomas, B. (2003). "Models of Operational Training in Fighter Squadrons," Research Report, RAND Organization, Santa Monica, CA.

Bookheimer, W. (1996). "Predicting Naval Aviator Attrition Using Economical Data," Master's Thesis, Graduate School of Business and Public Policy, Naval Postgraduate School, Monterey, CA.

Crenshaw, Dan (1999). "Wingman Tactics," Available from http://www.combatsim.com/memb123/archive/htm/htm_arc5/wingman1.htm. Last accessed June 30, 2007.

"56th Operations Group Mission Description," Available from http://www.luke.af.mil/library/factsheets/factsheet.asp?id=5003. Last accessed August 27, 2007.

"F-16 Pilot Training, Air Force Instruction (AFI) 11-2F-F16," Available from http://www.f-16.net/downloads_file13.html. Last accessed September 20, 2007.

"FY2001 DoD Military Personnel Composite Standard Pay and Reimbursement Rates." Available from http://www.defenselink.mil/comptroller/rates/fy2001.html. Last accessed October 23, 2007.

Higer, M., MAJ., (2007, September 7). [Interview by Murat Mise]. http://www.baseops.net/militarypilot/. Last accessed August 15, 2007.

Kulunk, B., 2nd Lieutenant, (2007, September 1). [Interview by Murat Mise].

Law, A., Kelton, W. (2000), Simulation Modeling and Analysis, McGraw-Hill, New York, NY.

"Observations on the Air Force Flying Hour Program," Government Accounting Office (GAO), (1999), GAO/NSIAD-99-165.

"Officer Career Fields," Available from http://www.af.mil/news/airman/0106/00_PDFs/58-59_Career_Fields.pdf. Last accessed August 3, 2007.

Rennspies, Norman (2002). "Formation Flying," Available from http://www.apstraining.com/article6_fci_training_apr03.htm. Last accessed July 5, 2007.

Thaler, D., Dahlman C. (2002), "Assessing Unit Readiness," Case Study, RAND Organization, Santa Monica, CA.

"USAF Specialized Undergraduate Pilot Training (UPT) Pipeline," Available from

"US Air Force Cost and Planning Factors, Air Force Instruction AFI 65-503 (2001)," Department of the Air Force (2001).

"Wingman definition," Available from http://en.wikipedia.org/wiki/Main_Page. Last accessed September 12, 2007.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Robert Beck
   Graduate School of Business and Public Policy
   Naval Postgraduate School
   Monterey, California

4. Keebom Kang
   Graduate School of Business and Public Policy
   Naval Postgraduate School
   Monterey, California

5. Uday Apte
   Graduate School of Business and Public Policy
   Naval Postgraduate School
   Monterey, California

6. Aruna Apte
   Graduate School of Business and Public Policy
   Naval Postgraduate School
   Monterey, California

7. Murat Mise
   Turkish Navy General Staff
   Ankara, Turkey